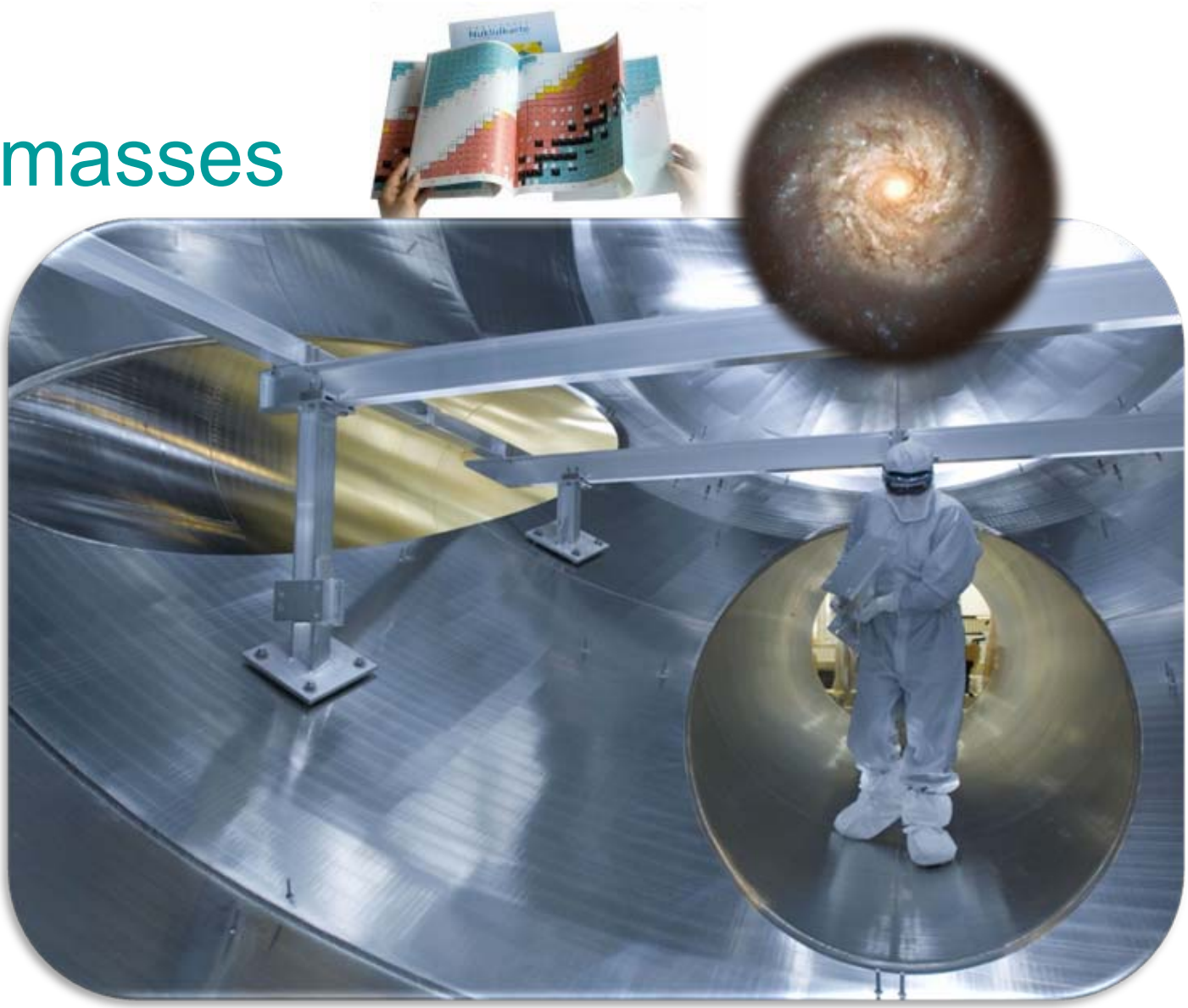
KATRIN:

hunting neutrino masses

ν´s in astroparticle physics
KATRIN
- principle
- main components
- sensitivity

Outlook



KIT – die Kooperation von
Forschungszentrum Karlsruhe GmbH
und Universität Karlsruhe (TH)

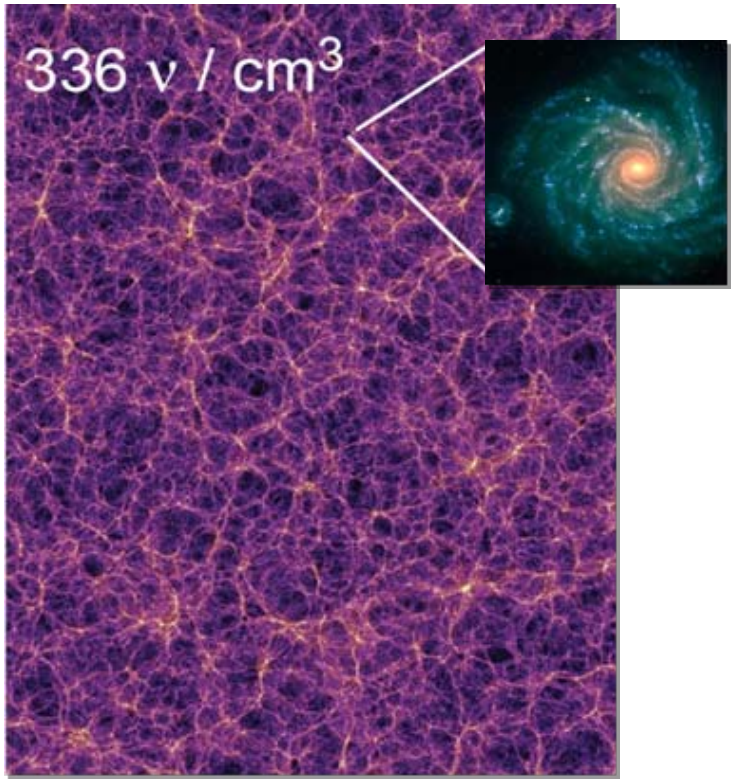
Universität Karlsruhe (TH)
Forschungsuniversität • gegründet 1825

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

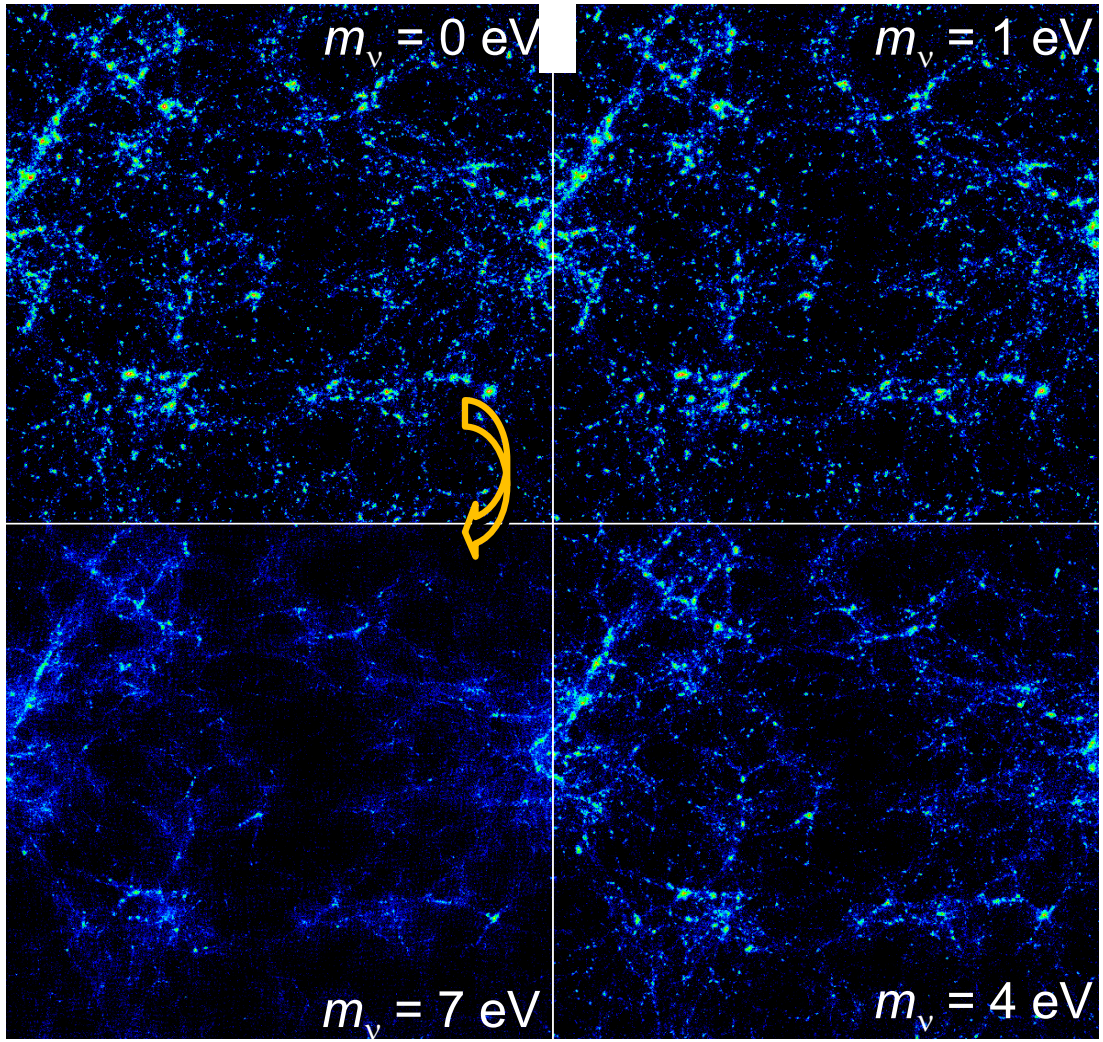
motivation: ν´s in astroparticle physics

cosmic architects: role of relic ν´s as hot dark matter?
large scale structures: free streaming of ν´s on Gpc scales

cosmology



structure of the universe
(Millenium Simulation)

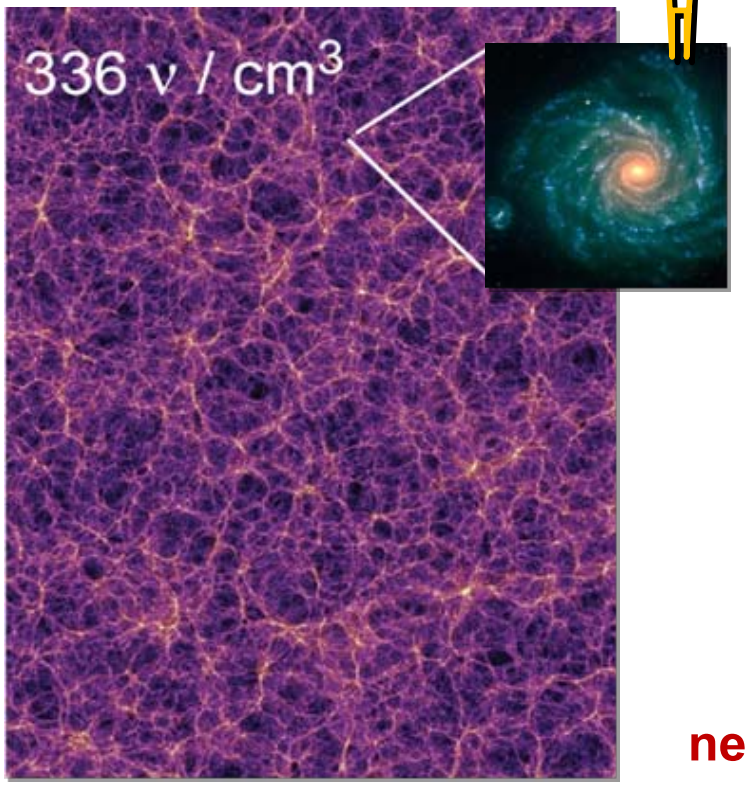


motivation: ν´s in astroparticle physics

cosmic architects: role of ν´s as hot dark matter?

microscopic keys: origin of the ν-mass?

cosmology



structure of the universe
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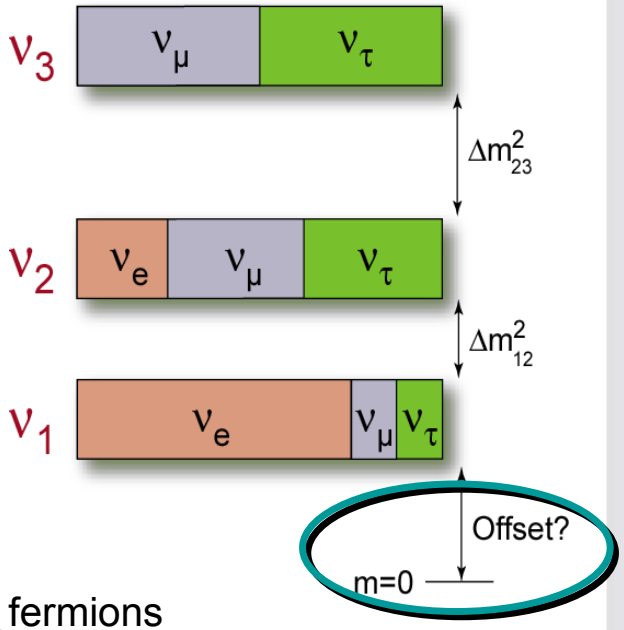
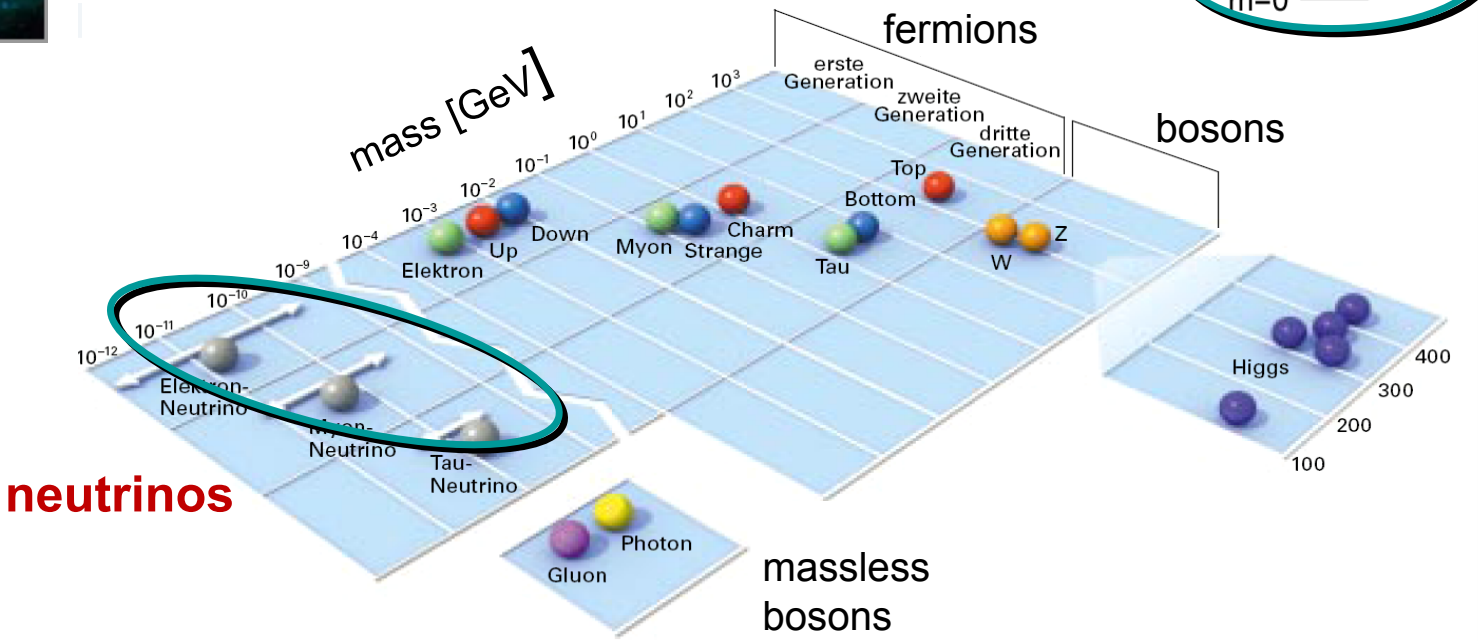
particle physics

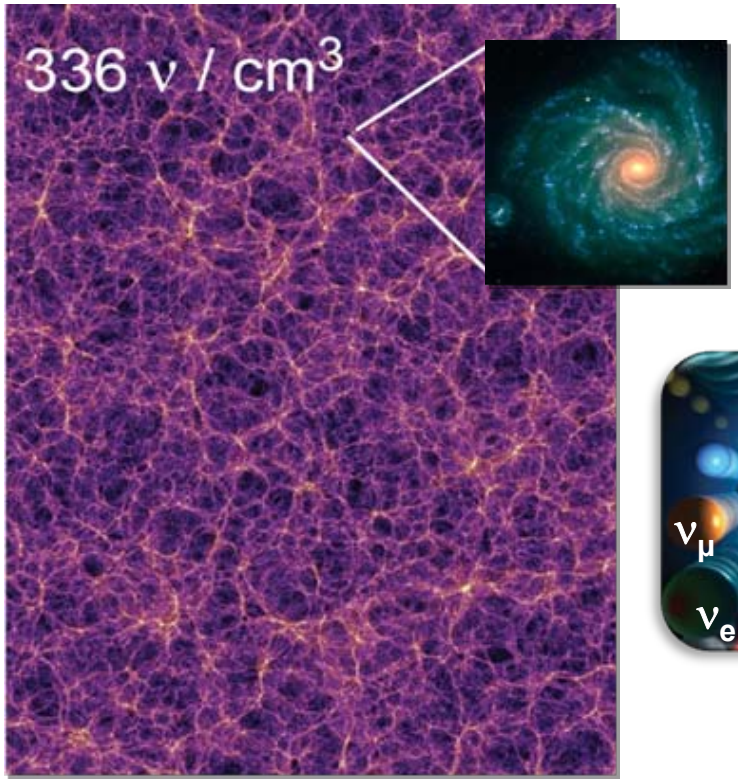




motivation: ν´s in astroparticle physics

cosmic architects: role of relic ν´s as hot dark matter?

$\Omega_\nu h^2 = \Sigma m_\nu / 92$ eV



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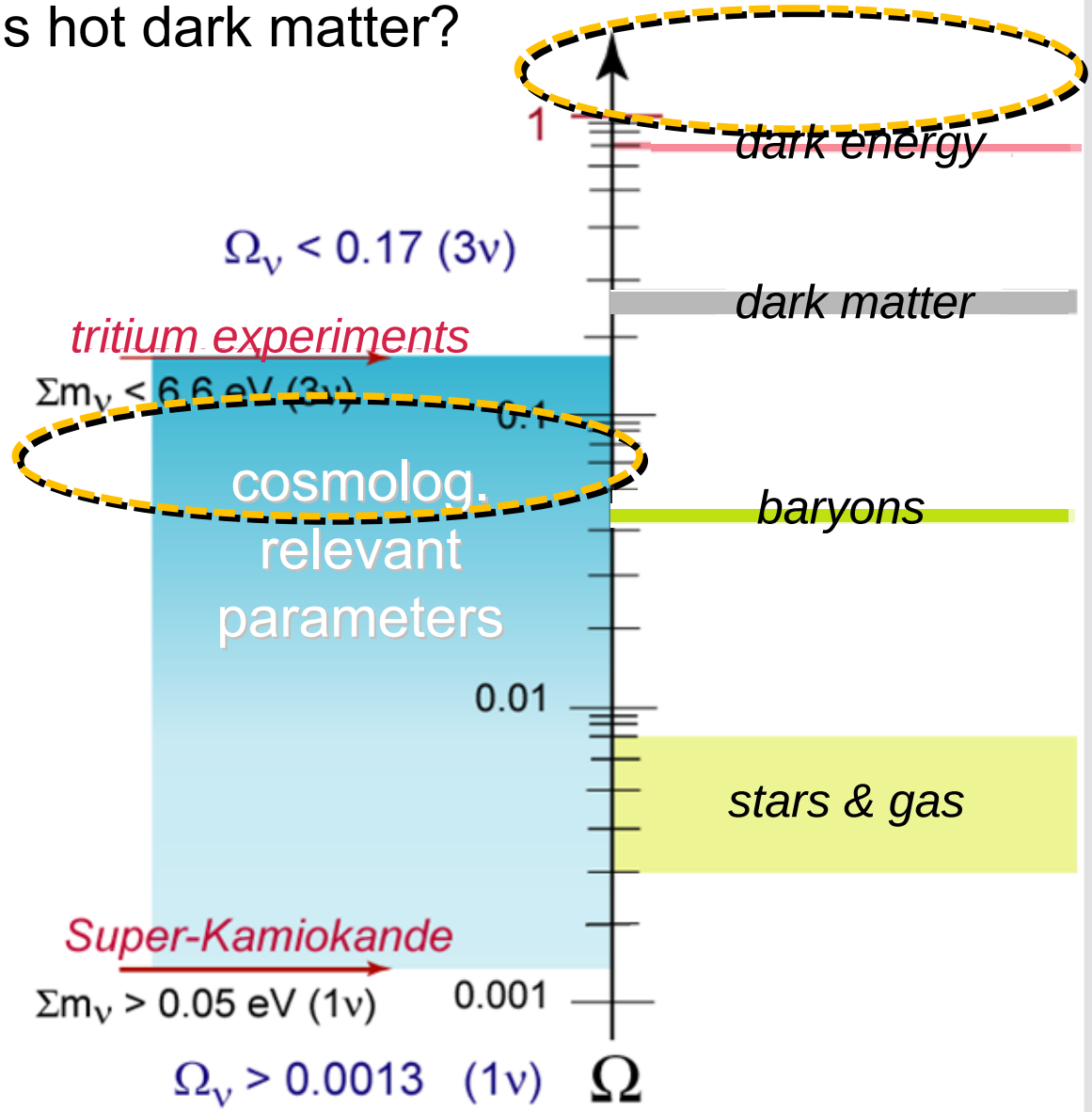
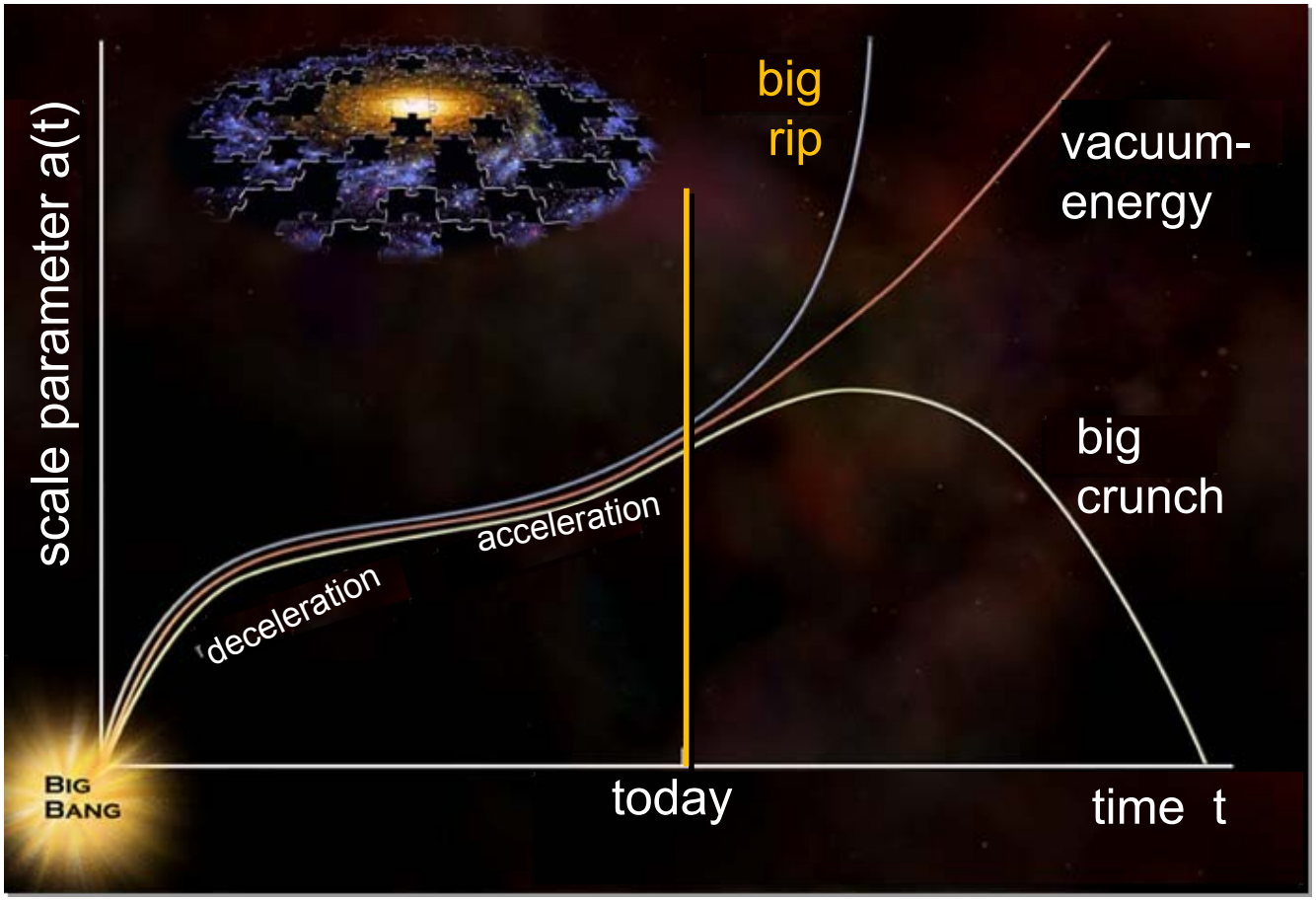


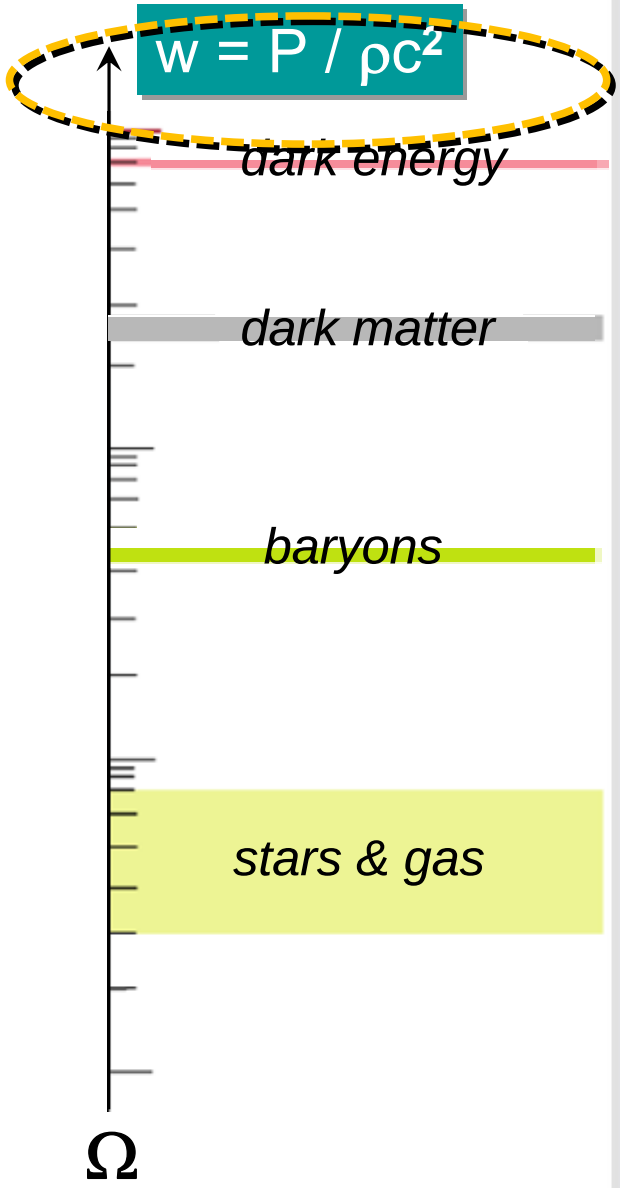
motivation: ν´s in astroparticle physics

cosmic architects: role of relic ν´s as hot dark matter?

microscopic keys: origin of the ν-mass?

m_ν could fix dark energy equation of state w



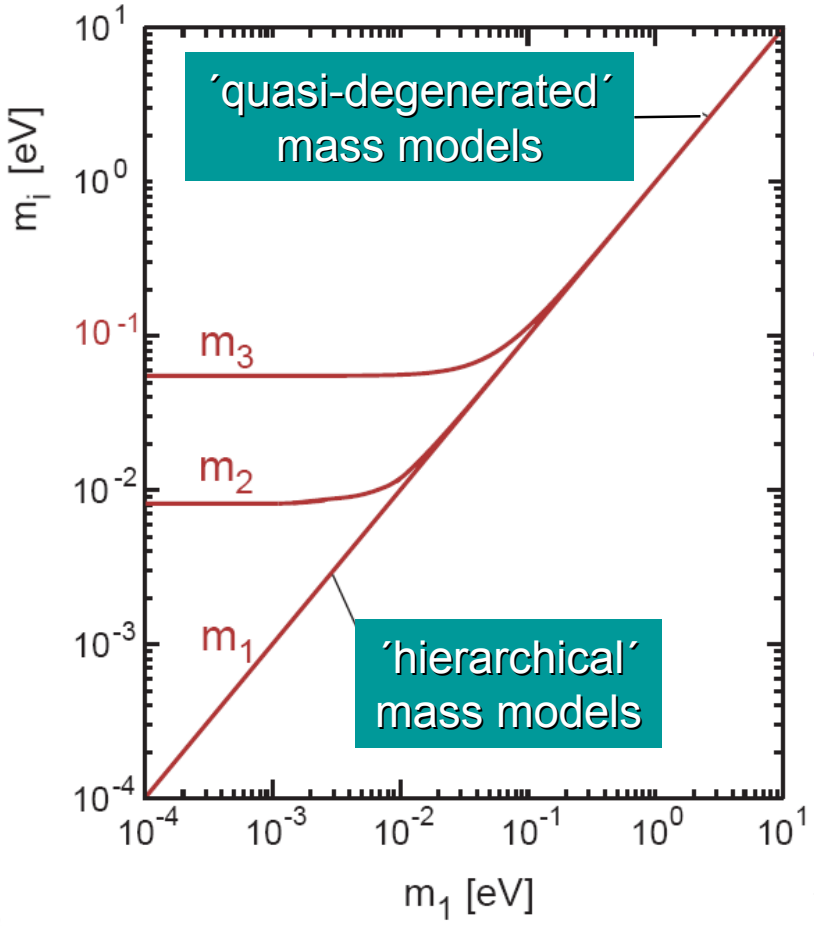


motivation: ν´s in astroparticle physics

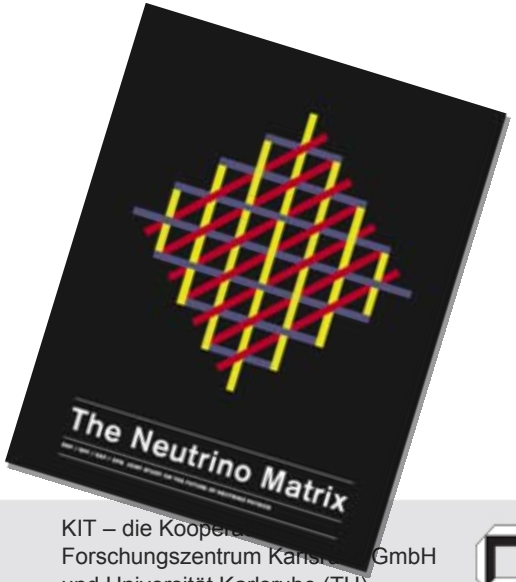
microskopic keys: origin of the ν-mass?

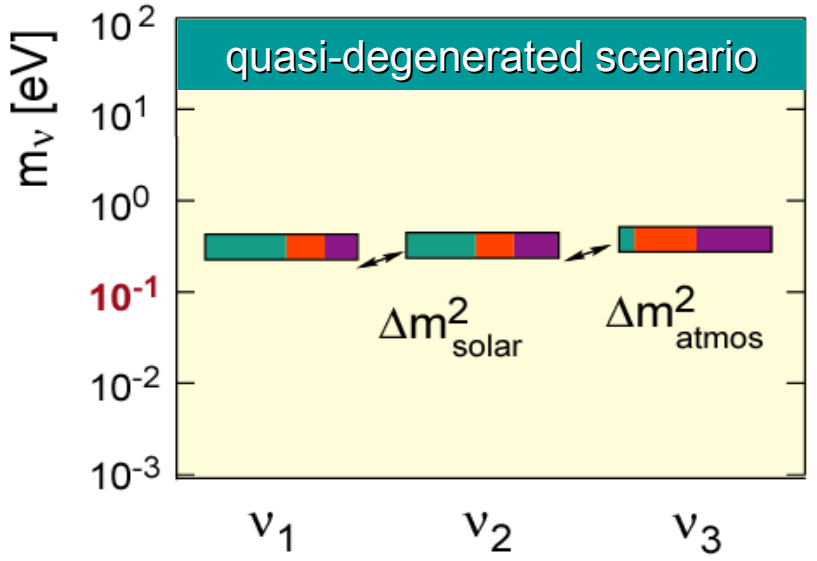
m(ν) most important parameter for ν-theory!

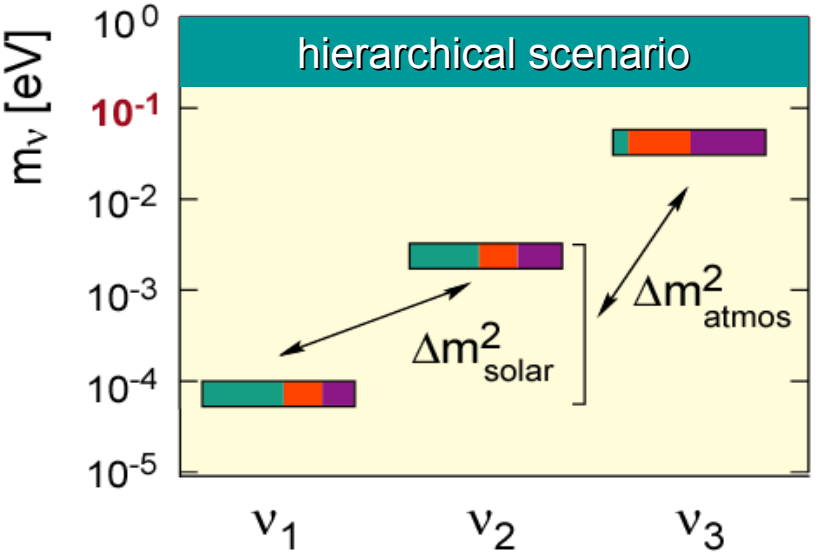
particle physics



see-saw models:
Typ I-II-III ?
extra dimensions?
triplett-Higgs?
family symmetry?







neutrino mass: status and perspectives

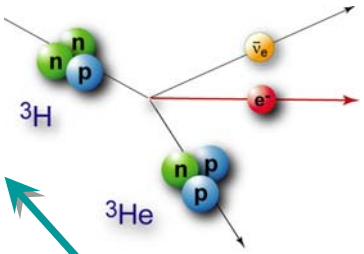
kinematics of ß-decay
absolute ν_e-mass: m_ν

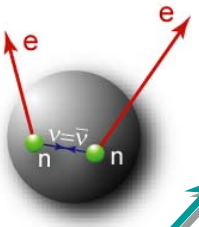
model-independent

status: $m_\nu < 2.3$ eV

potential: $m_\nu = 200$ meV

KATRIN (MARE-II)





search for 0νßß
eff. Majorana mass $m_{ßß}$

model-dependent (CP-phases)

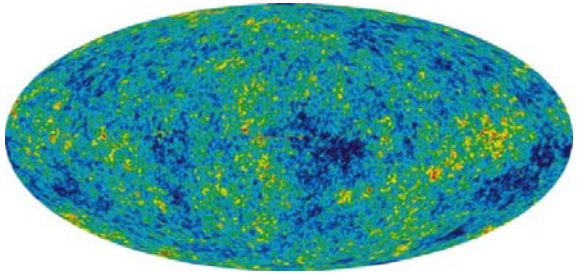
status: $m_{ßß} < 0.35$ eV, evidence?

potential: $m_{ßß} = 20$-50 meV

GERDA, EXO, CUORE

neutrino masses
experimental techniques:
status & potential

cosmology
sum Σm_i, HDM Ω_ν



model-dependent (multi-parameter fits)

status: $\Sigma m_i < 1$ eV [Hannestad et al., arXiv:0803.1

potential: $\Sigma m_i = 20$-50 meV

Planck, LSST, weak lensing

ß-decay: Fermi´s theory & ν-mass

a model-independent measurement of m(ν_e)
based on kinematics & energy conservation

$$m(\nu_e) = \sqrt{\sum_{i=1}^{3} |U_{ei}^2| \cdot m_i^2}$$

incoherent sum

$$\frac{d\Gamma_i}{dE} = C \cdot p \cdot (E + m_e) \cdot (E_0 - E) \cdot \sqrt{(E_0 - E)^2 - m_i^2} \; F(E,Z) \cdot \theta(E_0 - E - m_i)$$

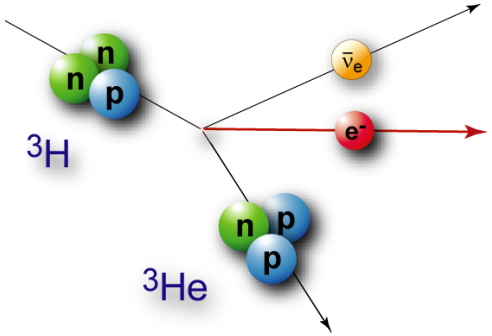
which isotope?

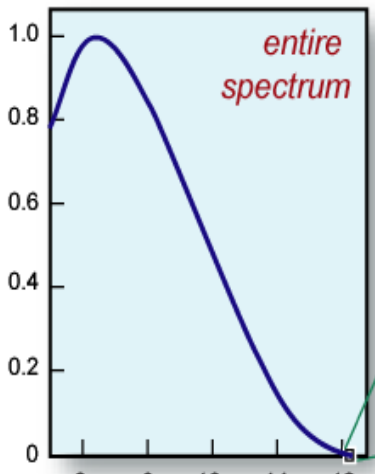
(ν– mass)²

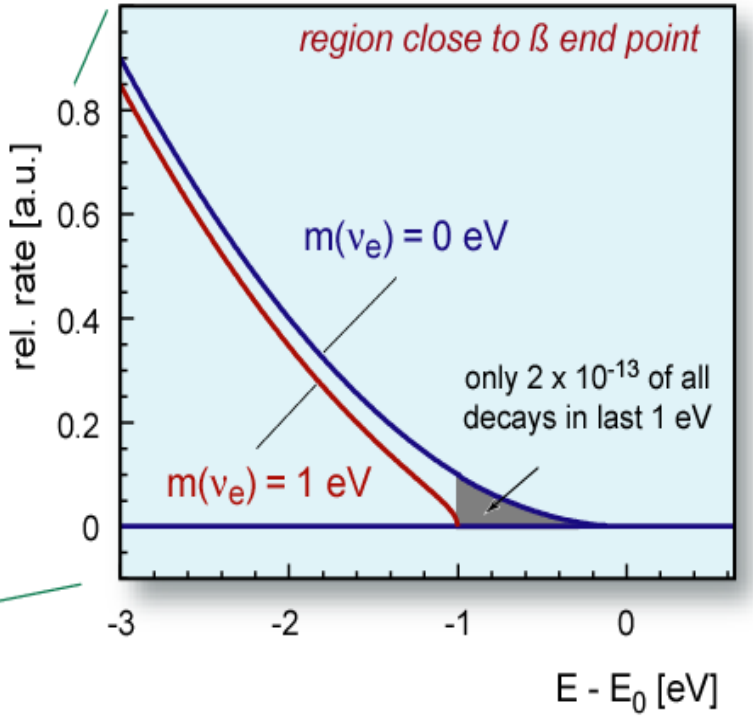
Fermi´s theory

^{3}H: super-allowed	
E_0	18. 6 keV
$t_{1/2}$	12.3 y

$^3H \rightarrow {}^3He + e^- + \bar{\nu}_e$



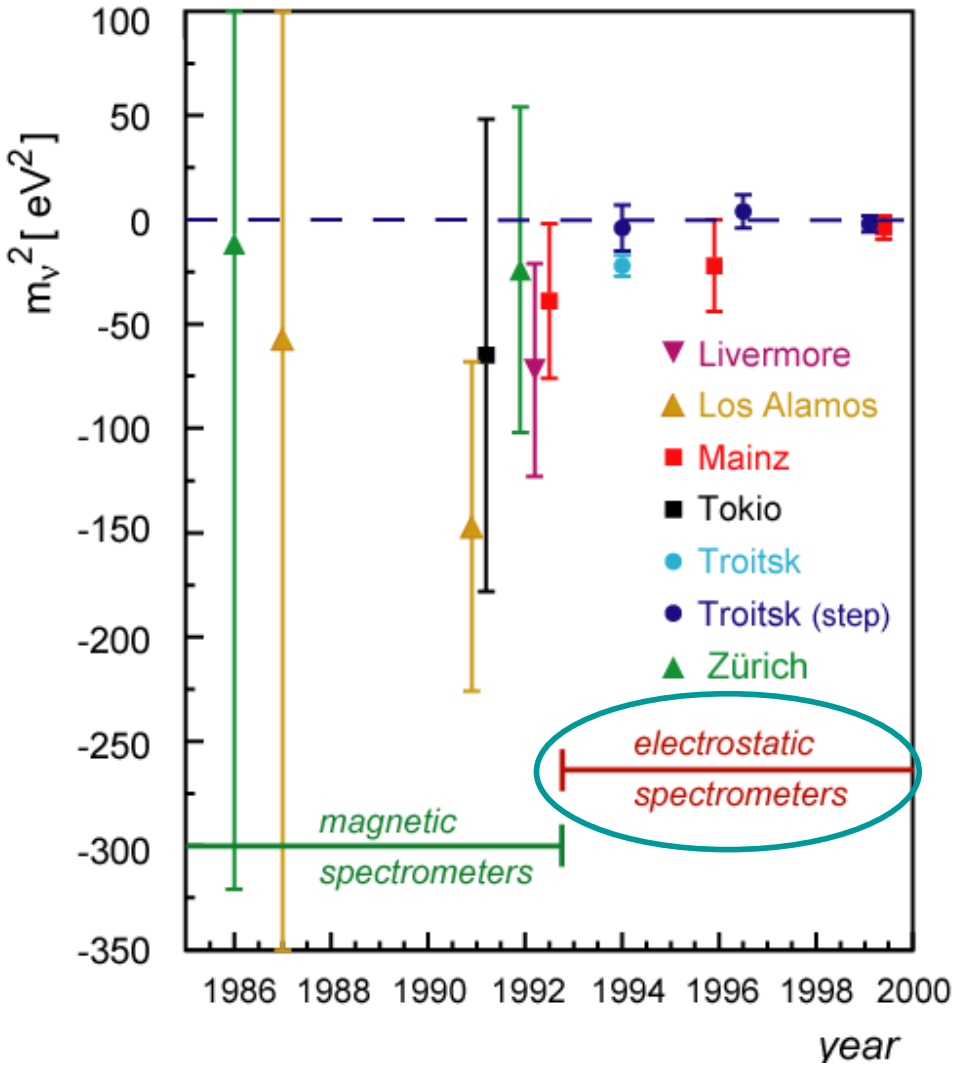




history of tritium ß-decay experiments

	m_ν
ITEP *T_2 in complex molecule* *magn. spectrometer (Tret'yakov)*	17-40 eV
Los Alamos *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 9.3 eV
Tokio *T - source* *magn. spectrometer (Tret'yakov)*	< 13.1 eV
Livermore *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 7.0 eV
Zürich *T_2 - source impl. on carrier* *magn. spectrometer (Tret'yakov)*	< 11.7 eV
Troitsk (1994-today) *gaseous T_2 - source* *electrostat. spectrometer*	< 2.3 eV
Mainz (1994-today) *frozen T_2 - source* *electrostat. spectrometer*	< 2.3 eV

experimental results for m_ν^2



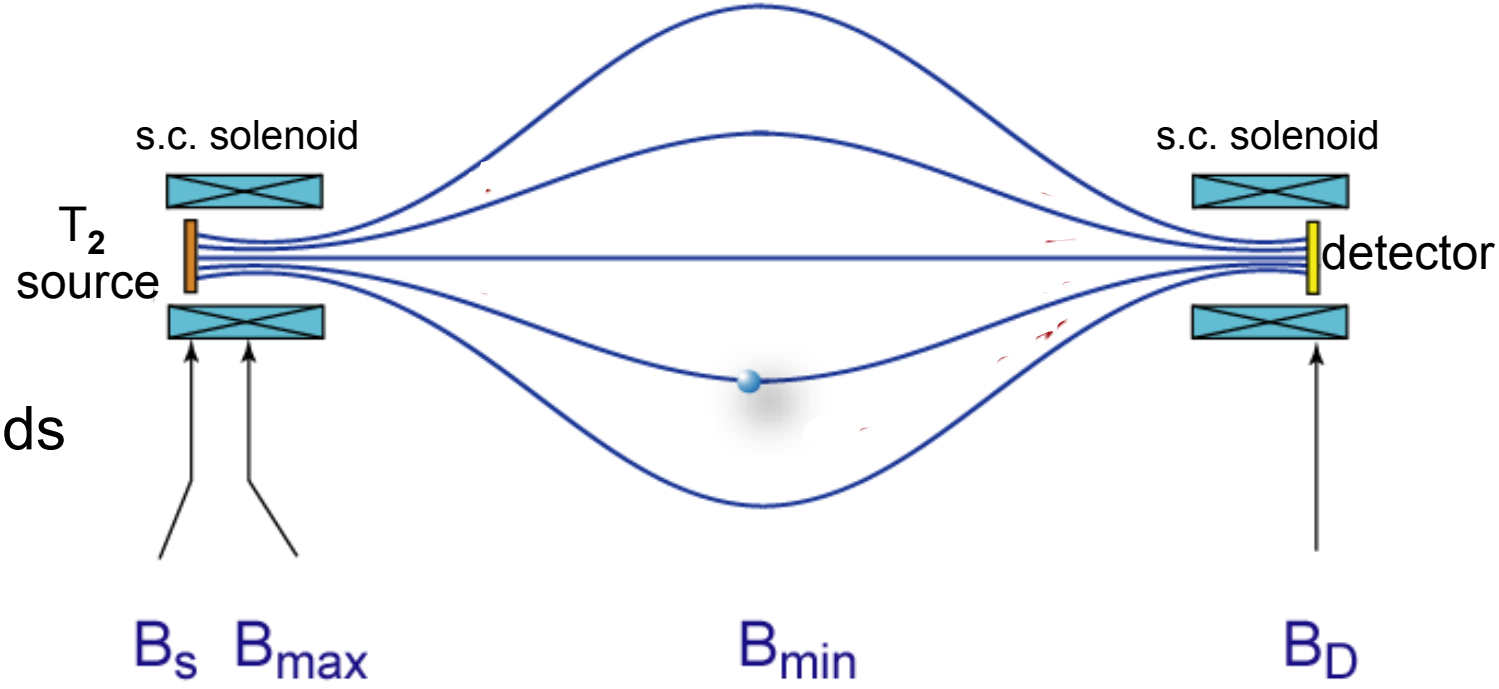
MAC-E filter – principle

MAC – Magnetic Adiabatic Guiding

adiabatic guiding
of electrons along
magnetic field lines

inhomogenous B-field:
superconducting solenoids
B_{max} = 3 – 6 T
B_{min} < 1 mT
solid angle $d\Omega \sim 2\pi$

$$\vec{F} = \left(\vec{\mu} \cdot \vec{\nabla}\right)\vec{B} + q \cdot \vec{E}$$
$$\mu = E_{\perp} / B = const.$$



adiabatic transformation $E_{\perp} \rightarrow E_{||}$

MAC-E filter – principle

E Filter – Electro-static filter

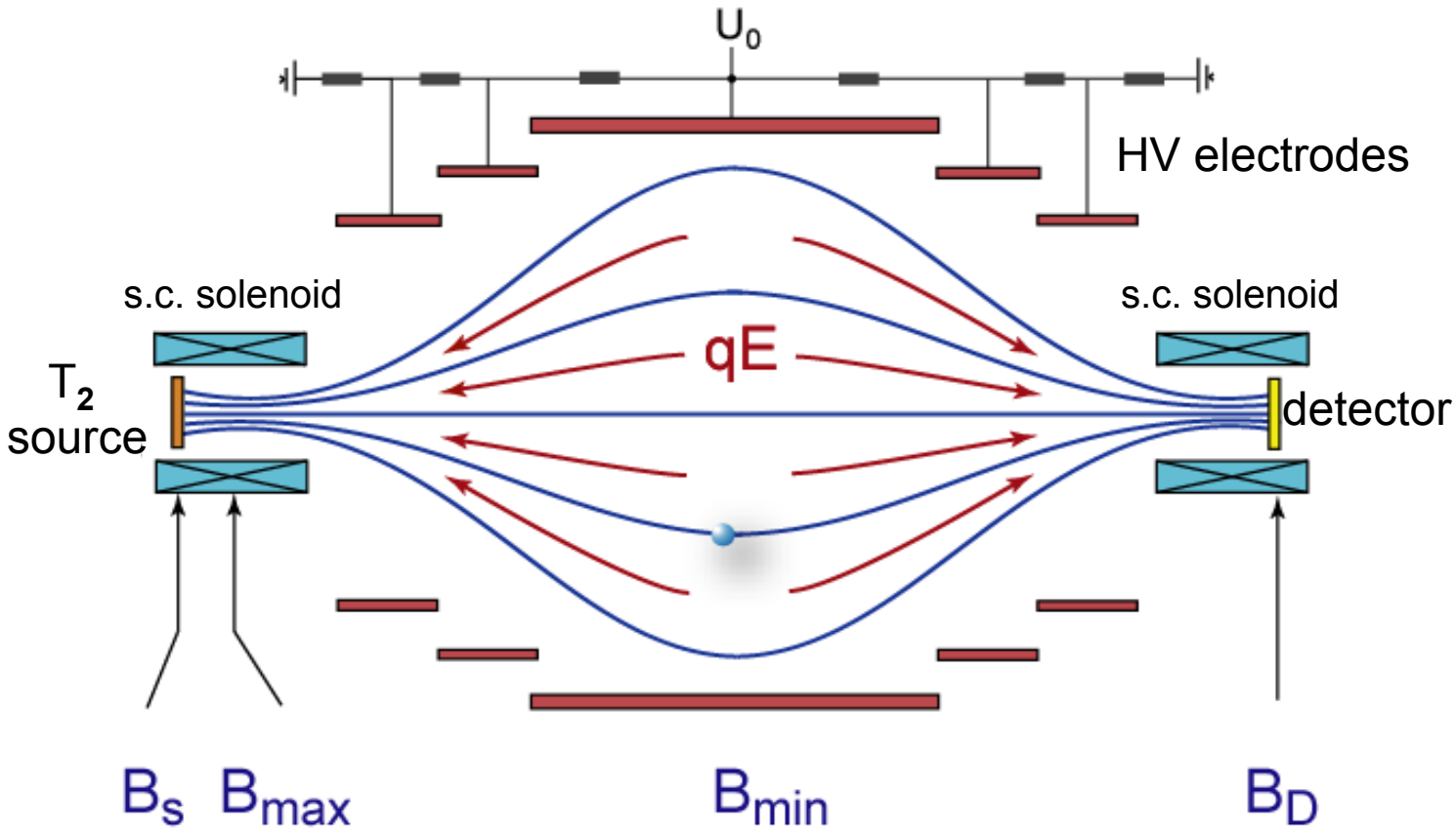
energy analysis by an electrostatic retarding field

variable E-field:
inner electrodes
U_0 = 18.5 – 18.7 kV

integral transmission for E > U_0
high pass filter

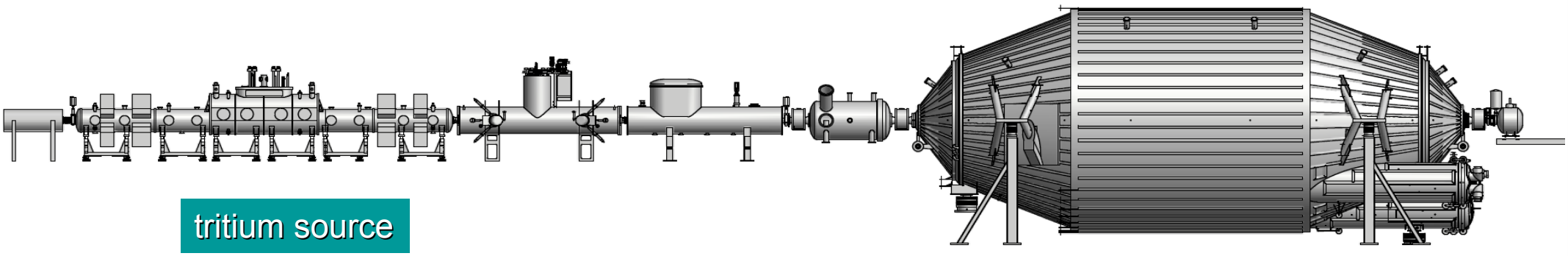
E Feld || B-Feld

conversion → retarding



adiabatic transformation $E_\perp \rightarrow E_{||}$

KATRIN – a MAC-E filter system



tritium source

adiabatic particle transport over 70 m

spectrometer

detector

ß-spectroscopy
with ΔE =0.93 eV

ultraluminous molecular
windowless gaseous
tritium source

1:20000

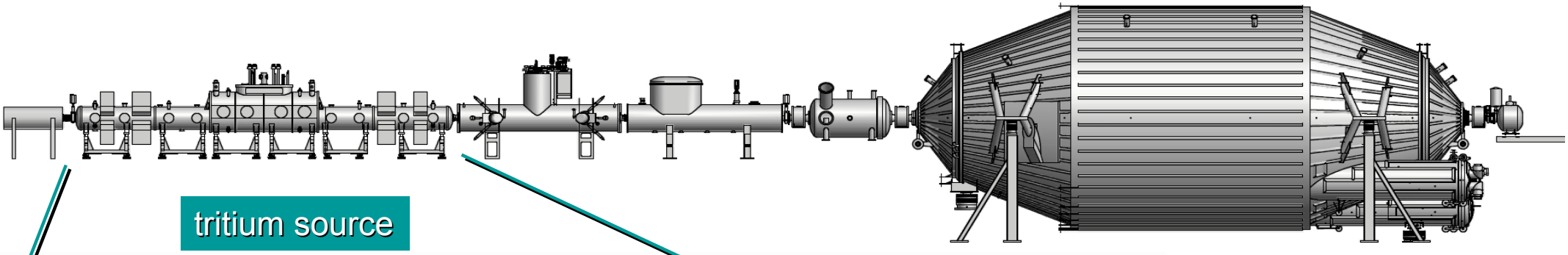
B-field [T]

1
10^{-1}
10^{-2}
10^{-3}

-40 -30 -20 -10 0 +10

distance from analysing plane [m]

KATRIN – windowless gaseous source



16 m long complex cryostat:

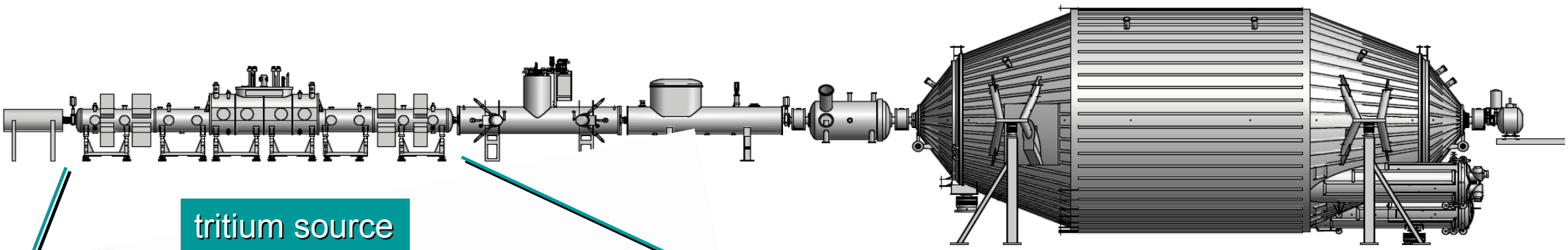
-12 cryogenic circuits

- 6 cryogenic fluids

- instrumentation:

~500 sensors for temperature (4 – 600 K), B-field, pressure, gas flow, liquid levels,…

KATRIN – windowless gaseous source



tritium source

WGTS	design value	precision
luminosity	1.7×10^{11} Bq	
injection rate	5×10^{19} mol/s	± 0.1 %
column density ρd	5×10^{17} mol/cm^2	± 0.1 %
tritium purity	> 95%	
magnetic field	3.6 T	± 2%

WGTS demonstrator (12m)

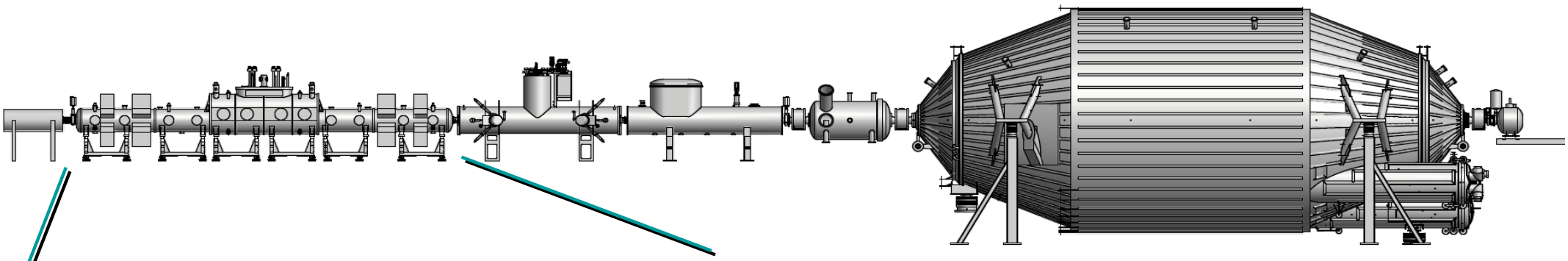
currently being assembled
delivery to TLK in June 2009

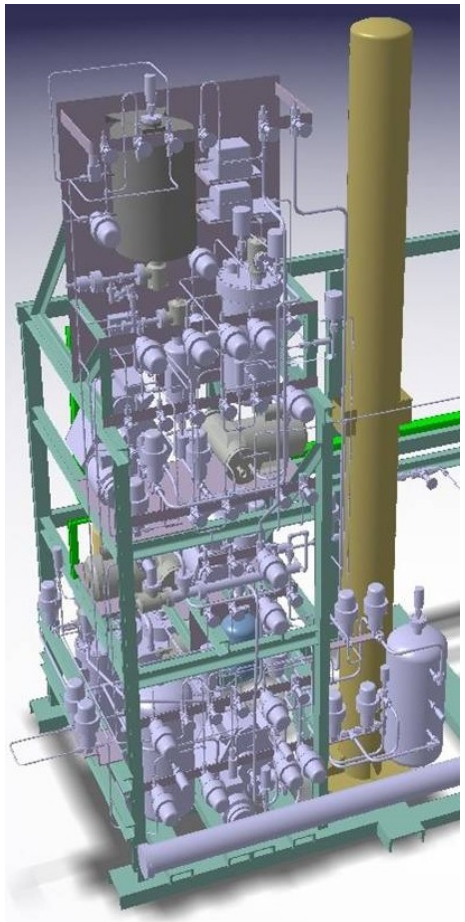
key technological challenge:
precise cooling of beam tube

⇨ temperature stabilsation of beam tube of 10^{-3}

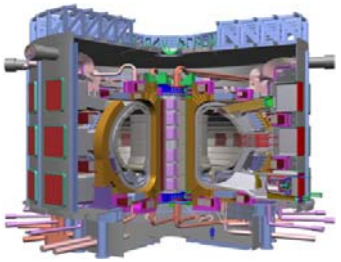
2-phase-Neon @ 27K

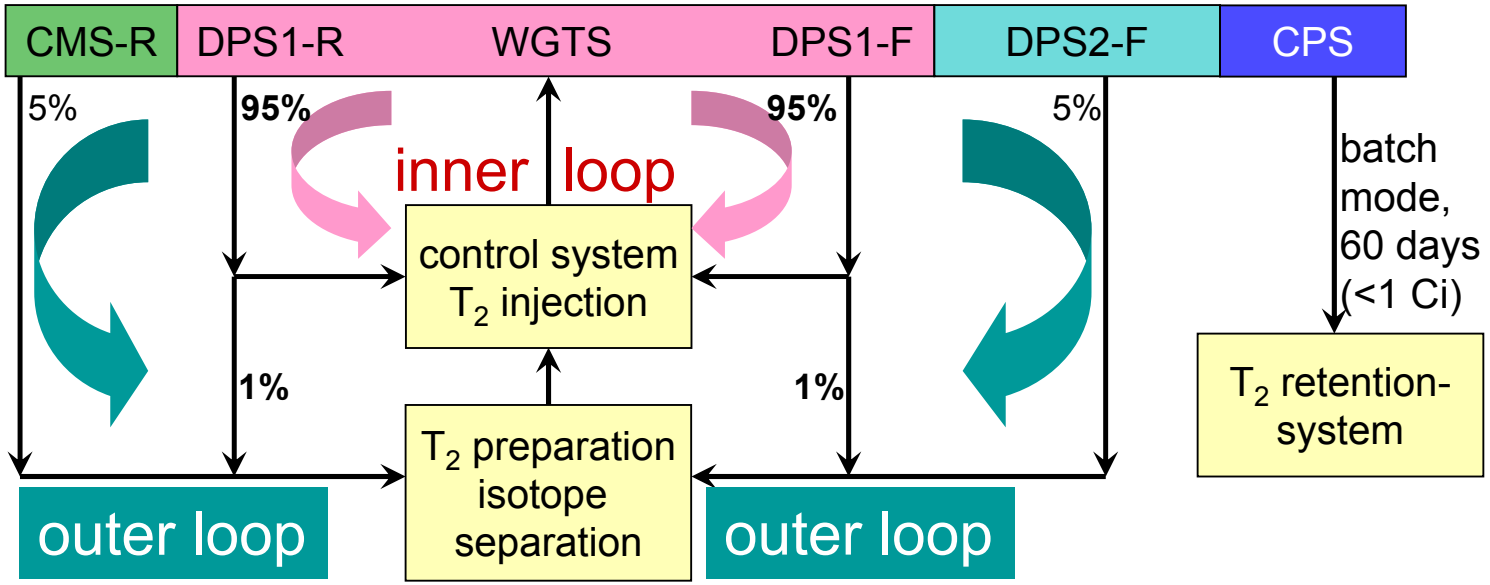
KATRIN – tritium infrastructure



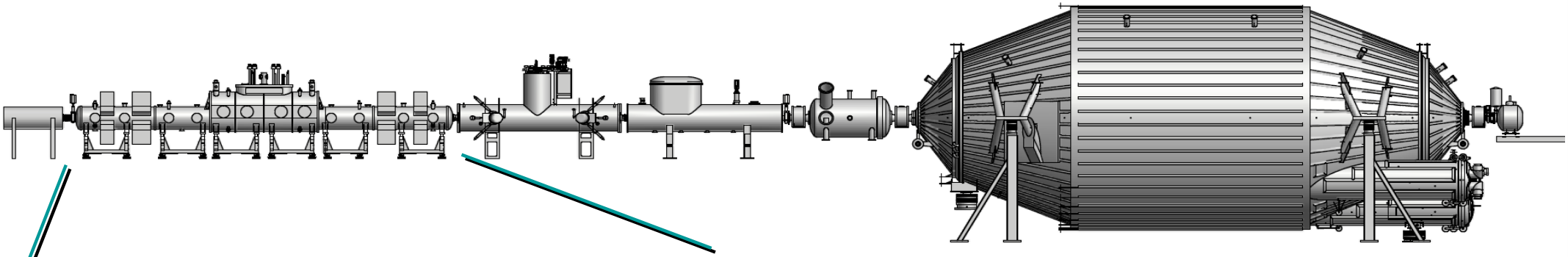


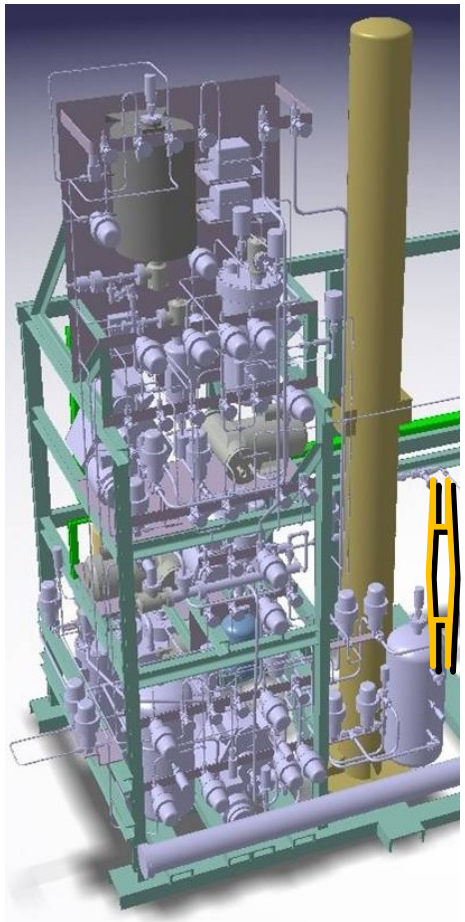
27 pumps, 109 valves
62 sensors, 6 buffer vessels
2 permeators
Tritium troughput/year equivalent to ITER



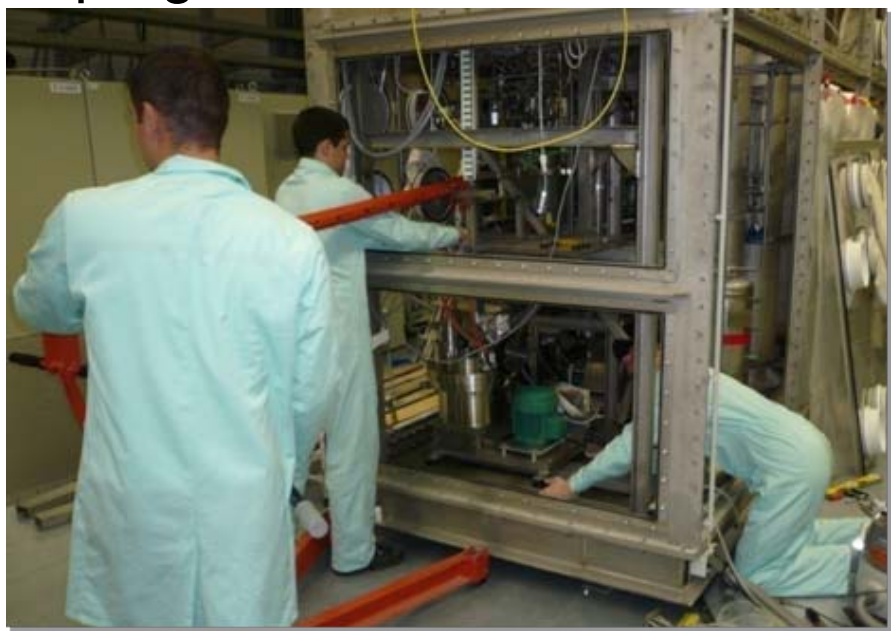


KATRIN – tritium infrastructure





set-up of inner loop system
in progress ☑

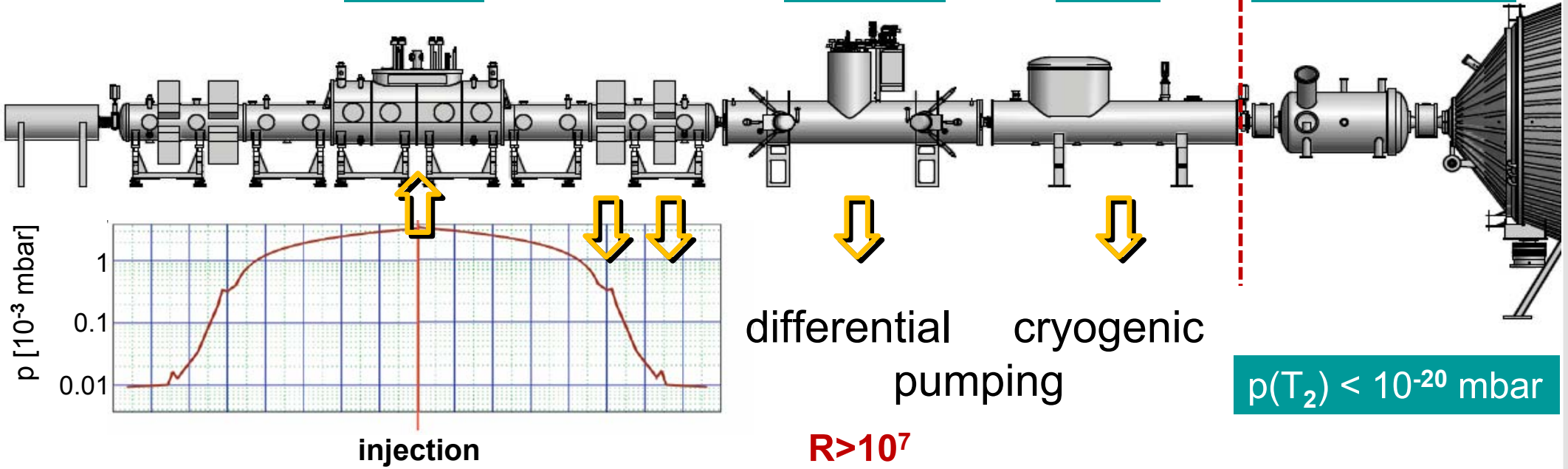


KATRIN – tritium retention

the tritium flow out of the WGTS has to be reduced by **factor ~10^{14}**

tritium bearing components | tritium free

WGTS | DPS2-F | CPS | spectrometers



differential pumping | cryogenic pumping

$p(T_2) < 10^{-20}$ mbar

injection rate = 1.8 mbar ℓ / s

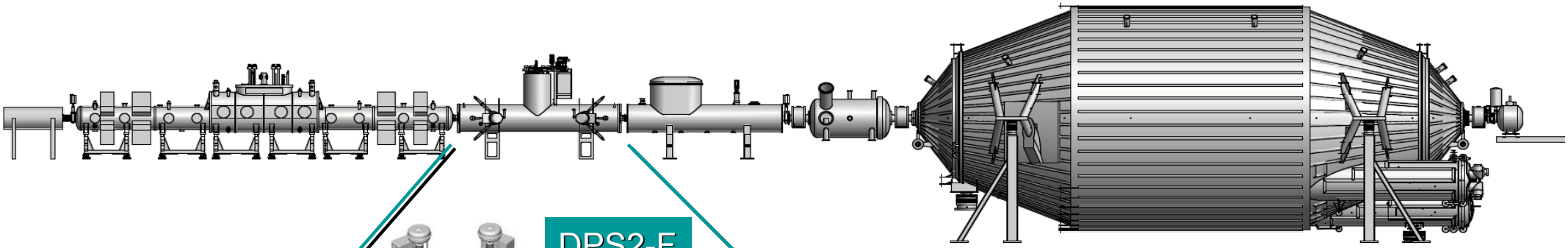
R>10^7

10^{-7} mbar ℓ/s

R>10^7

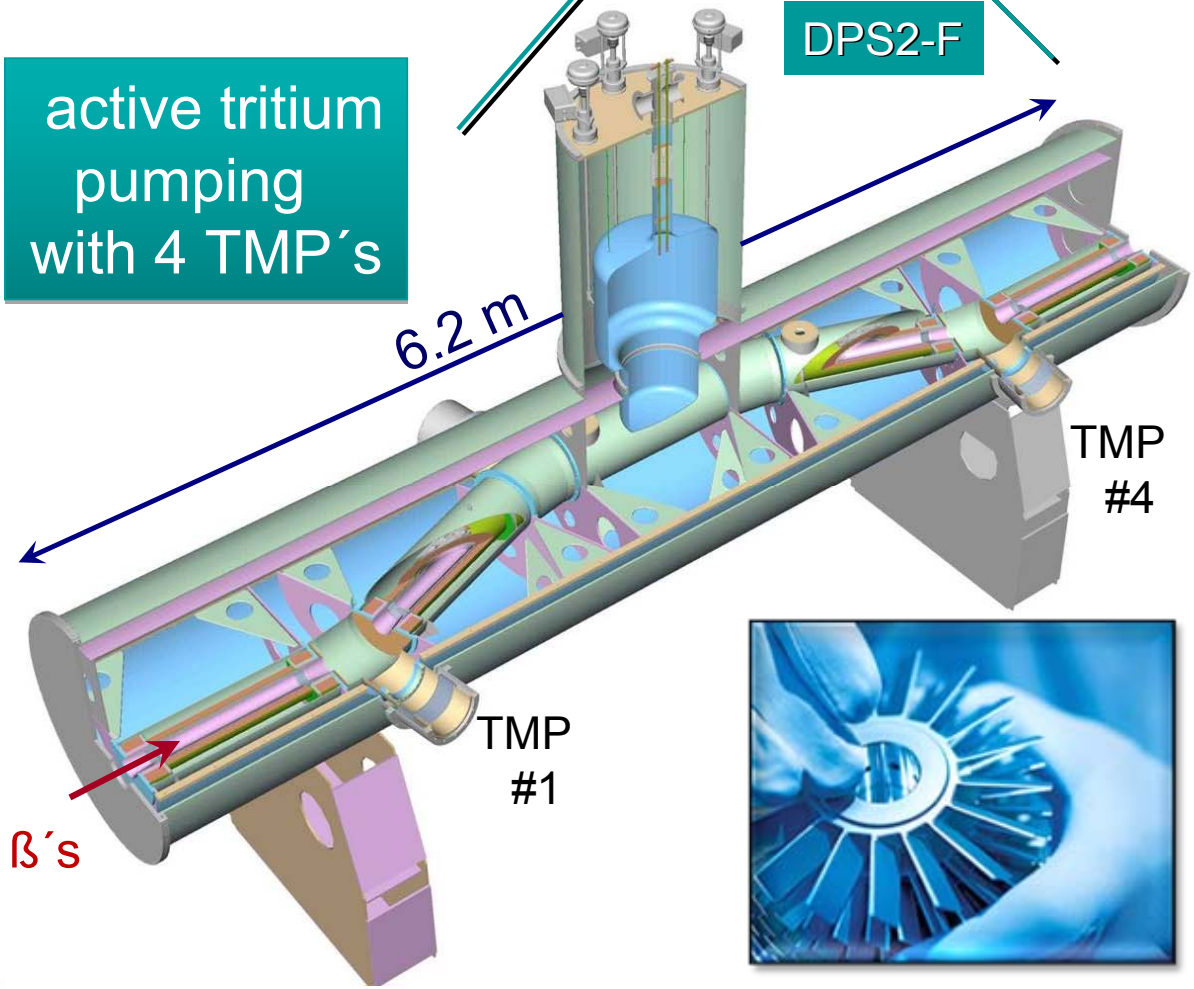
10^{-14} mbar ℓ/s

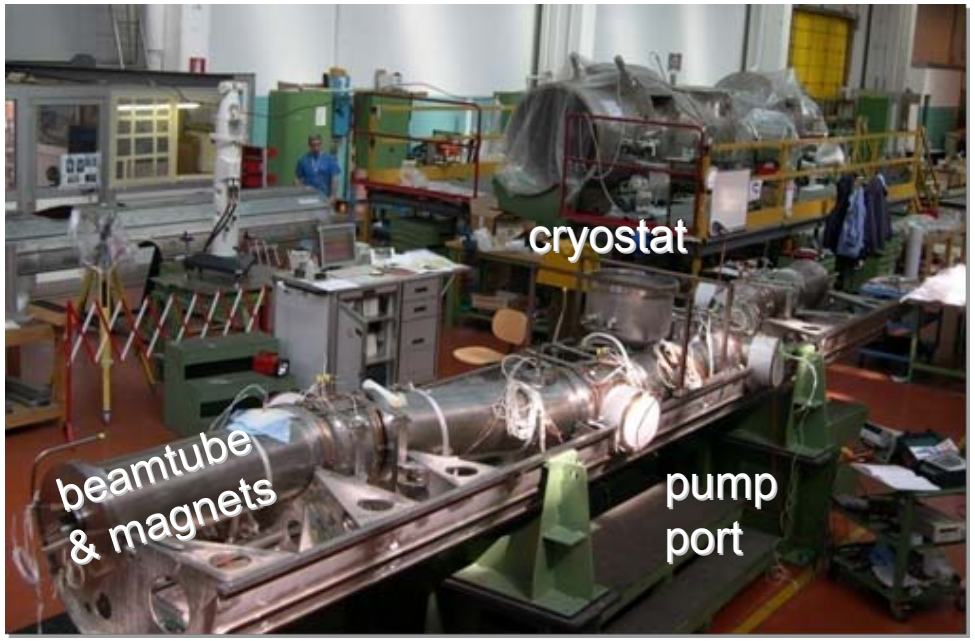
differential pumping section DPS2-F



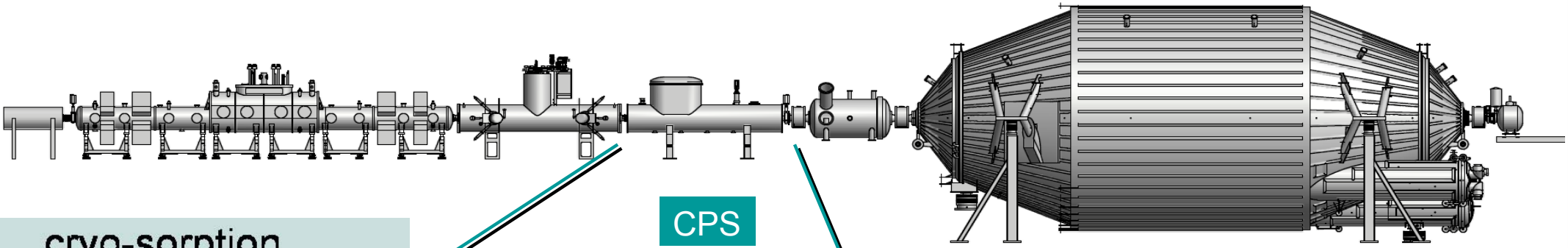
DPS2-F

active tritium pumping with 4 TMP´s

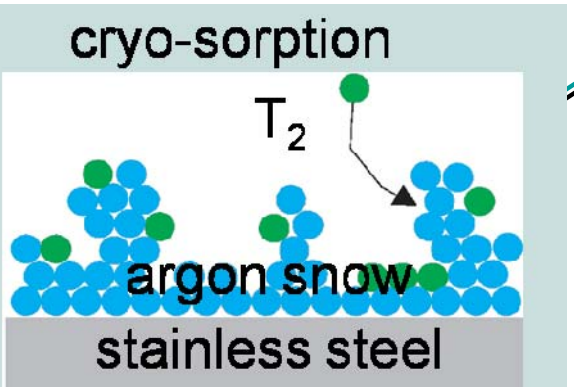


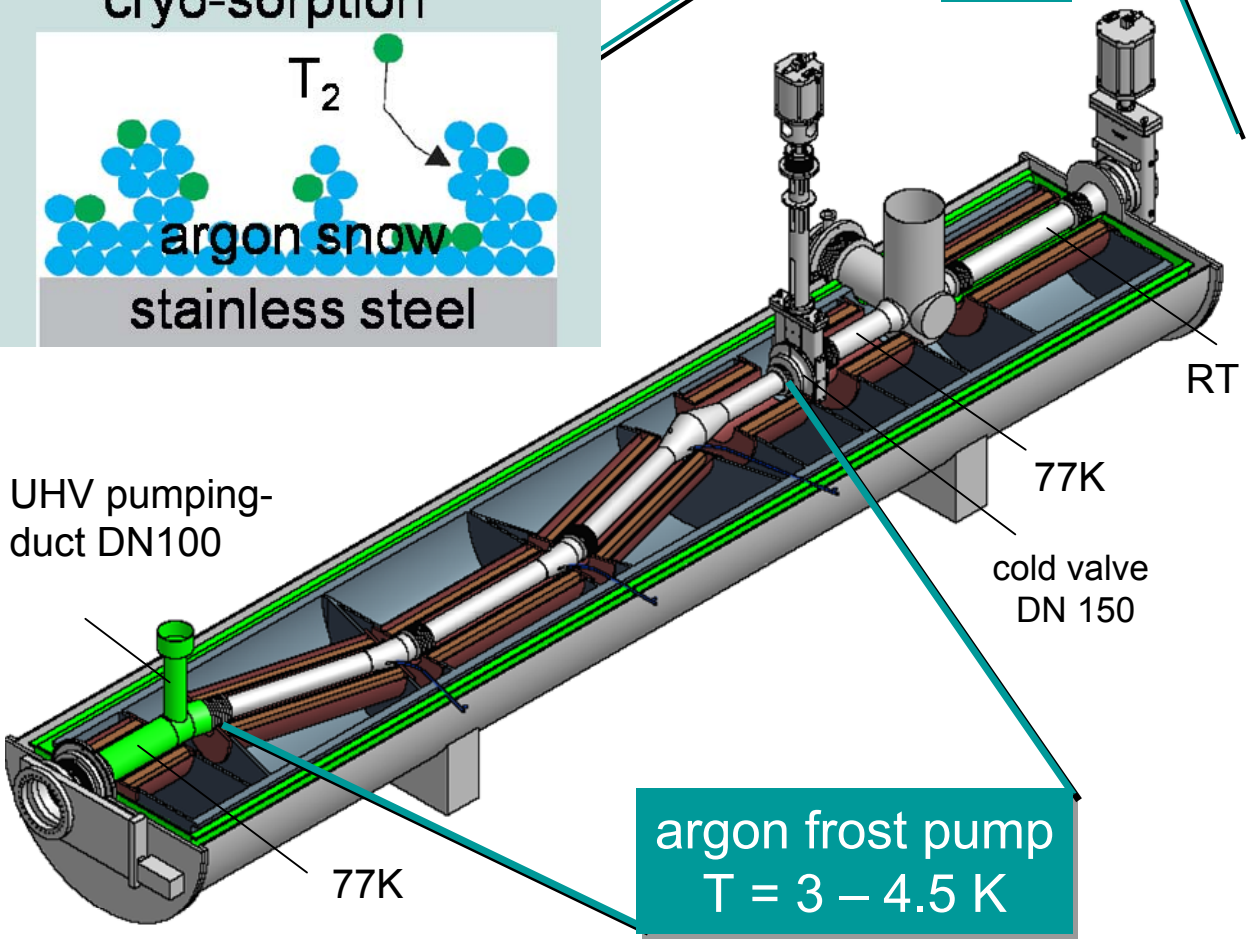


cryogenic pumping section CPS



CPS





argon frost pump
T = 3 – 4.5 K

objective: reduction of T_2-flux by factor 10^7 :
10^{-7} mbar ℓ/s →
10^{-14} mbar ℓ/s

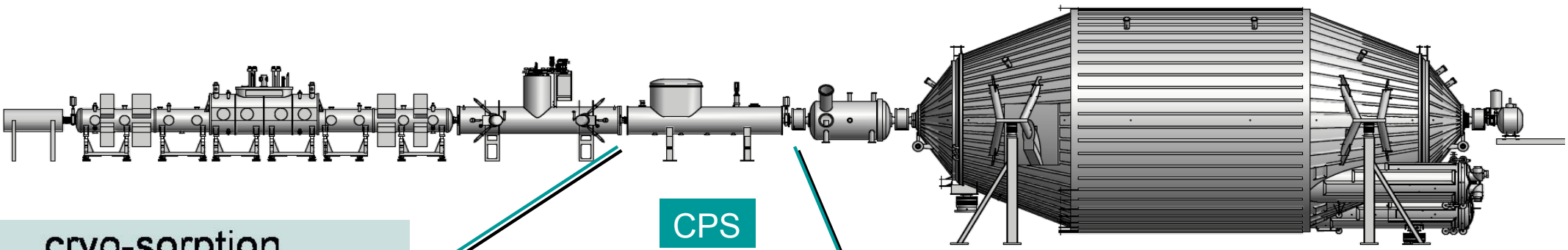
method: cryo-sorption on condensing Ar-frost

T_2-rate: <1 Ci T_2 in 60 days = 1 KATRIN run

(regeneration with warm He-gas)

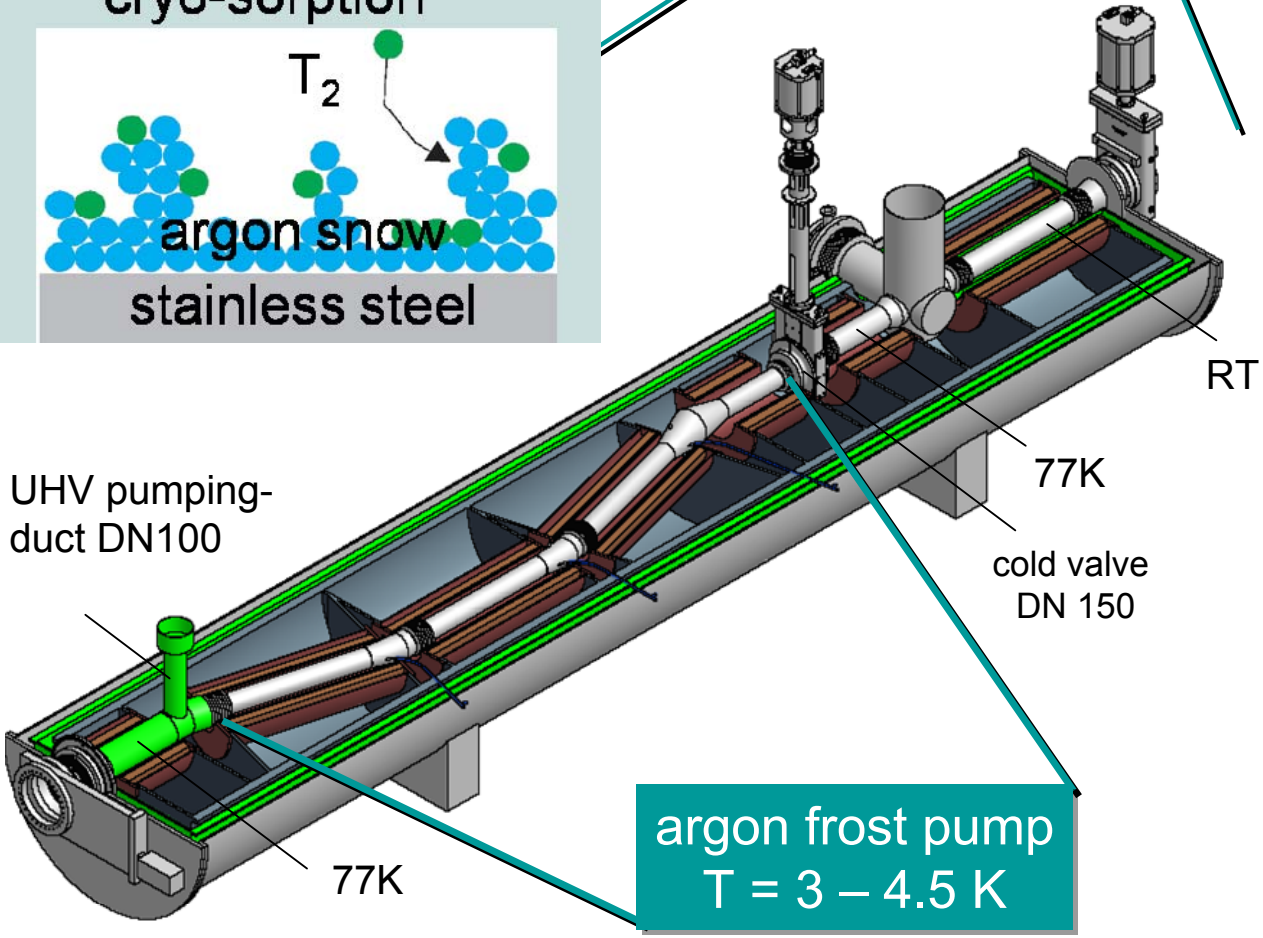
presently being manufactured by ASG

cryogenic pumping section CPS



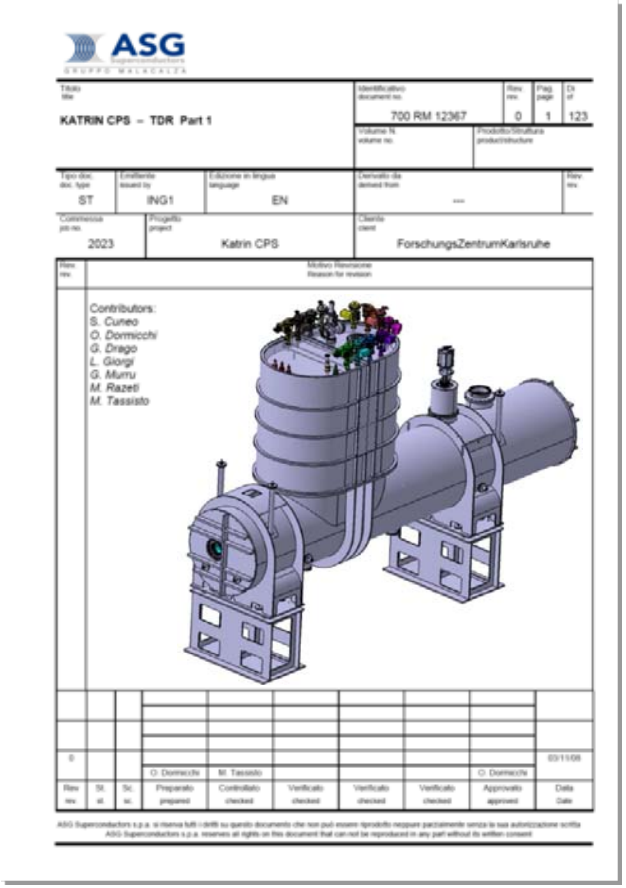
CPS

cryo-sorption

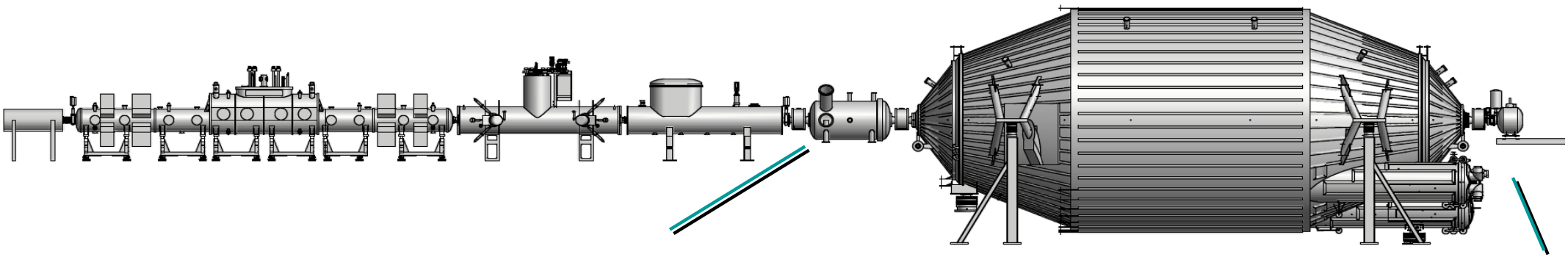


UHV pumping-
duct DN100

argon frost pump
T = 3 – 4.5 K



electrostatic spectrometers



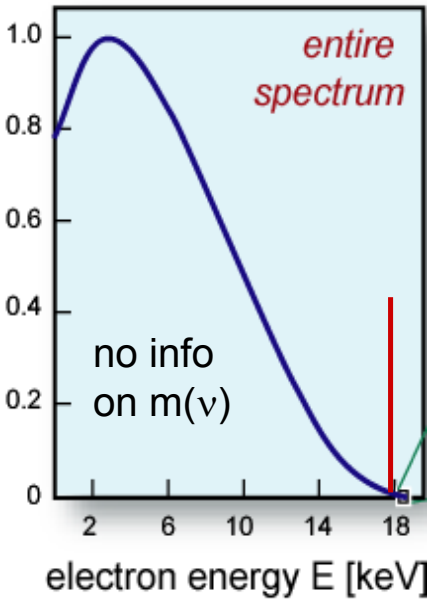
pre-filter

fixed retarding potential

U_0 = - 18.3 kV

ΔE ~ 100 eV

- filter out all ß-decay electrons without m(ν)-info
- reduce background from ionising collisions

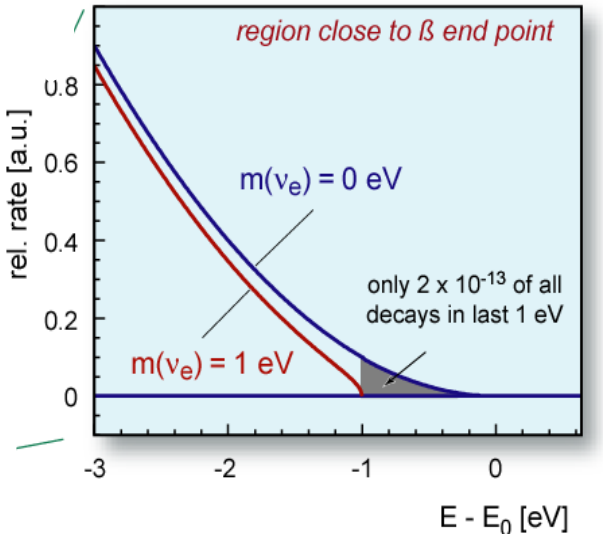


precision filter - scanning

variable retarding potential

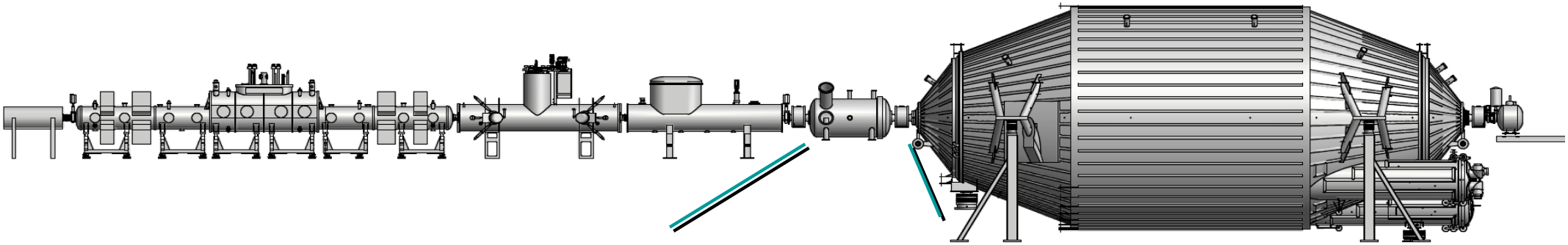
U_0 = - 18.4 … -18.6 kV

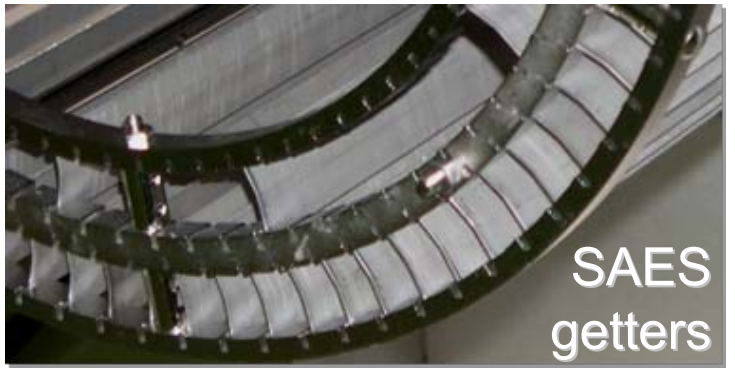
ΔE ~ 0.93 eV (100% transmission)



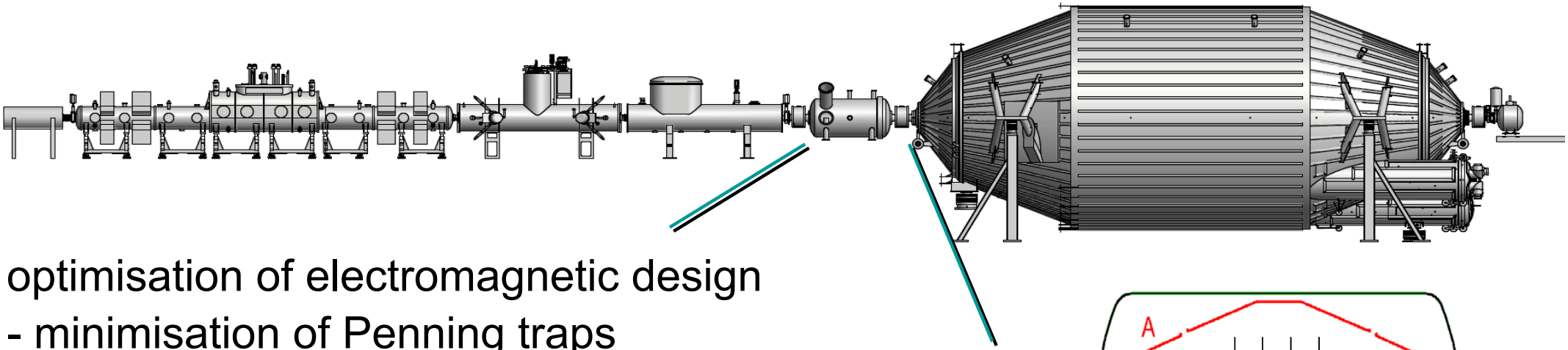
tandem design: pre-filter & energy analysis

pre-spectrometer – UHV

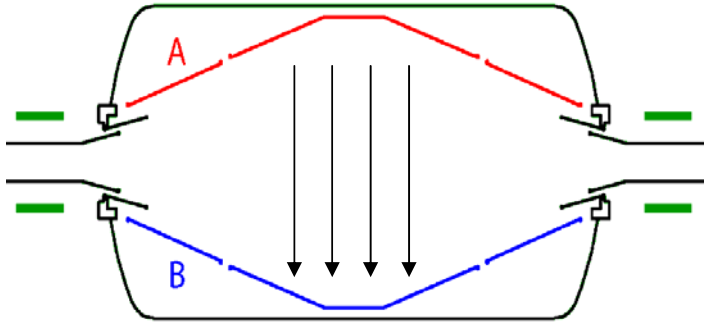




pre-spectrometer: electromagnetic tests

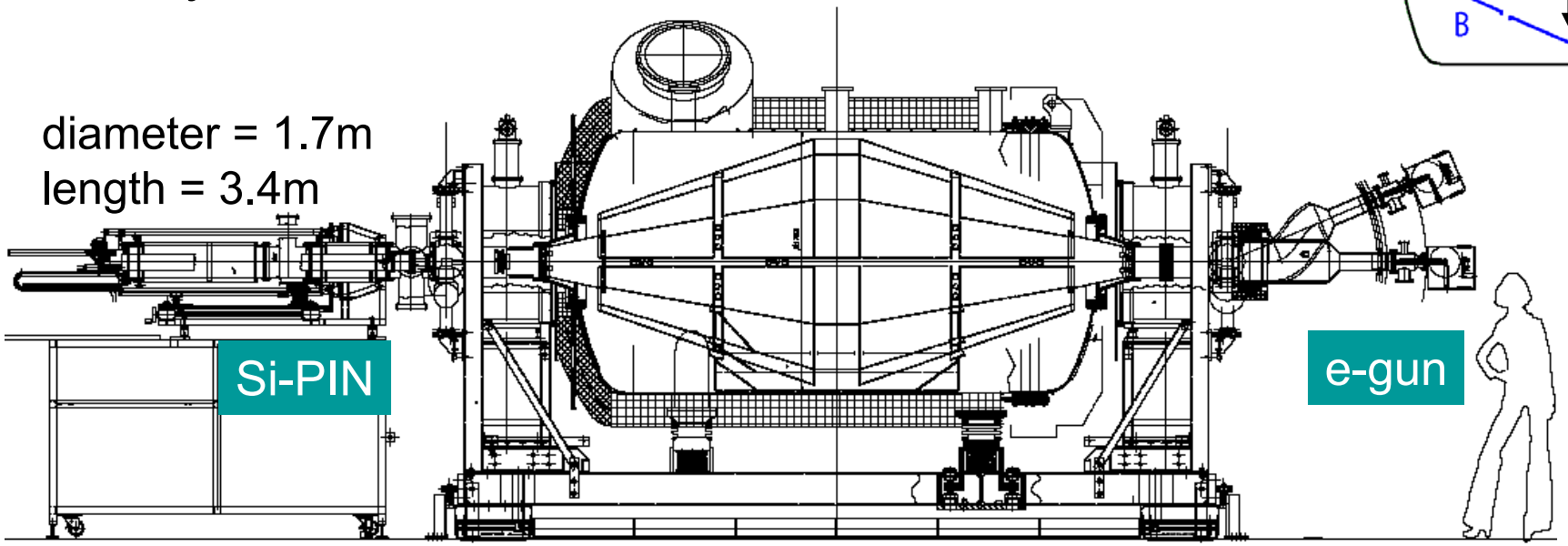


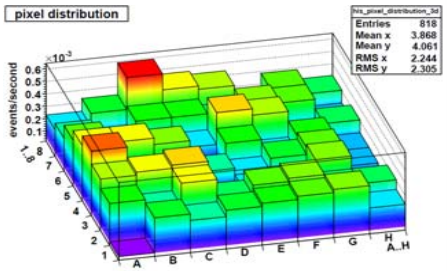
optimisation of electromagnetic design
- minimisation of Penning traps
- background reduction techniques (dipole fields)
- study of field emission



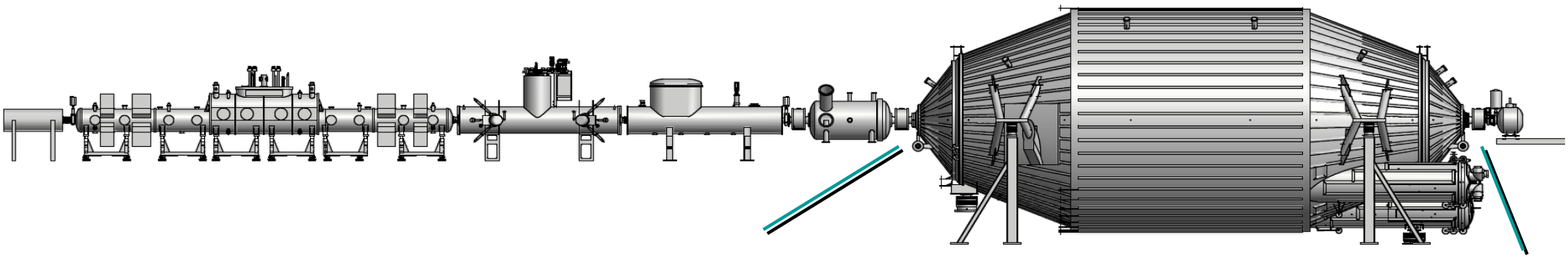
dipole fields

diameter = 1.7m
length = 3.4m



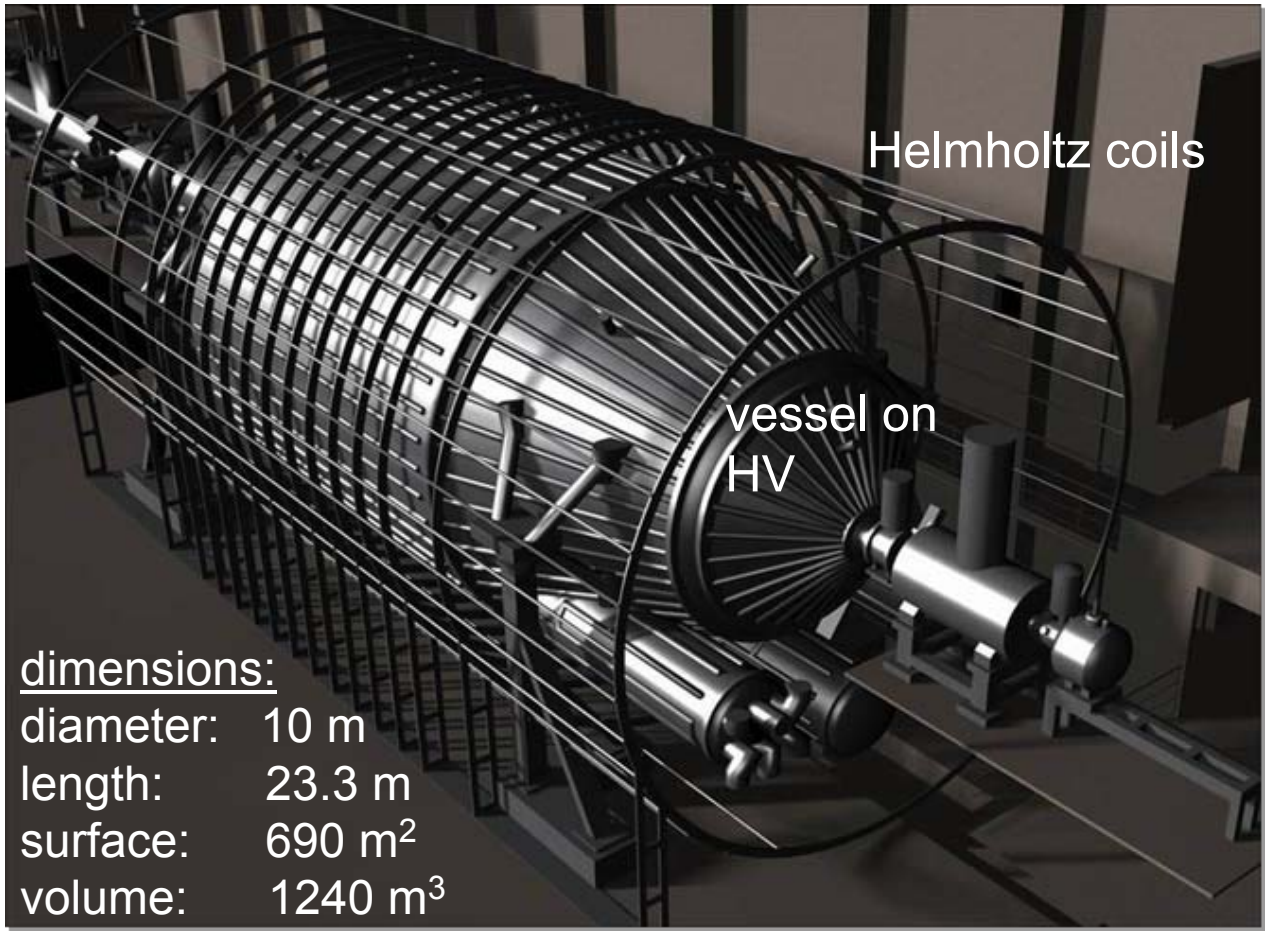


main spectrometer: world´s largest UHV recipient



UHV : p < 10^{-11} mbar !

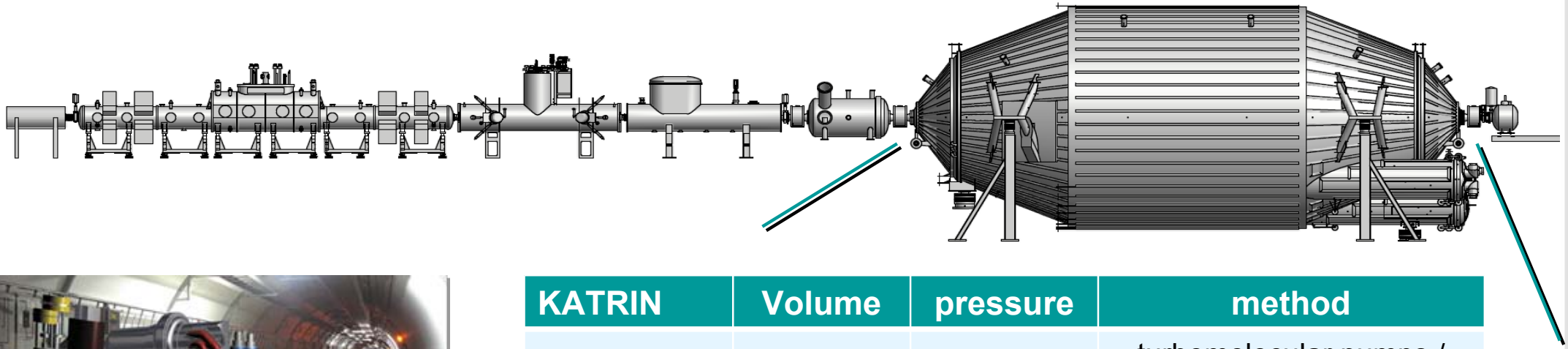
MAN DWE GmbH

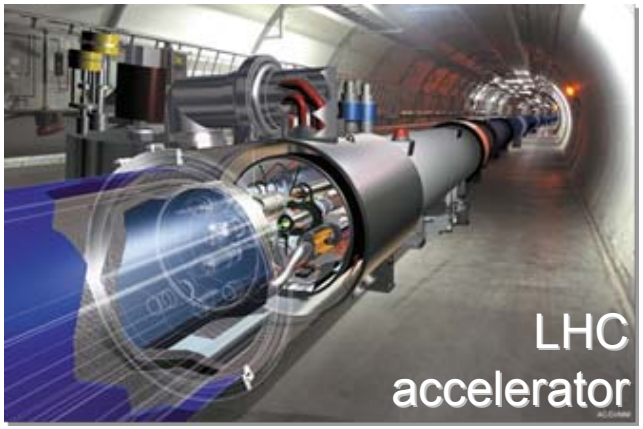


dimensions:

diameter:	10 m
length:	23.3 m
surface:	690 m^2
volume:	1240 m^3

main spectrometer: world´s largest UHV recipient





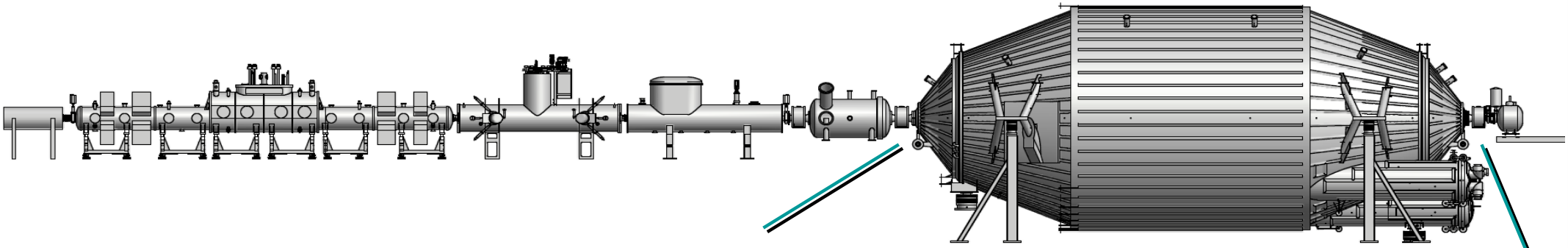
KATRIN	Volume	pressure	method
spectrometer	1250 m^3	10^{-11} mbar	turbomolecular pumps / nonevaporable getters

LHC	Volume	pressure	method
storage ring	154 m^3	10^{-11} mbar	cryocondensation on beam screen/magnet bore (1.9K)
cryogenic insulation	640 m^3	10^{-6} mbar	cryocondensation on magnet cold mass

LIGO	Volume	pressure	method
2x4km arms	8000 m^3	~10^{-8} mbar	ion pumps & cold traps

VIRGO	Volume	pressure	method
2x3km arms	6800 m^3	<10^{-9} mbar	titanium & ion pumps

main spectrometer: pre-acceptance tests

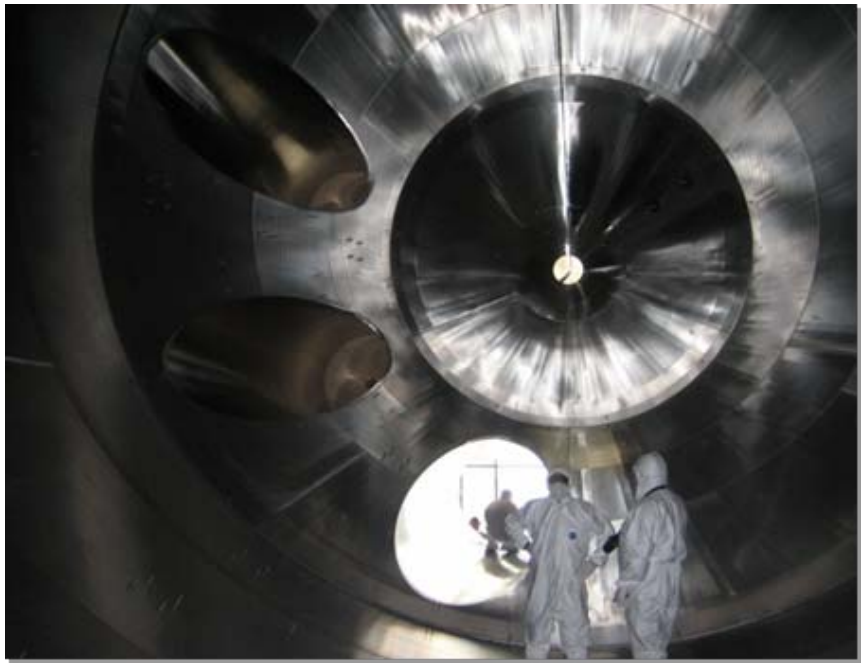


August 2006

1 TMP (WMAG2800)

$p < 6 \times 10^{-8}$ mbar

initial integral He-leak test at MAN-DWE ☑

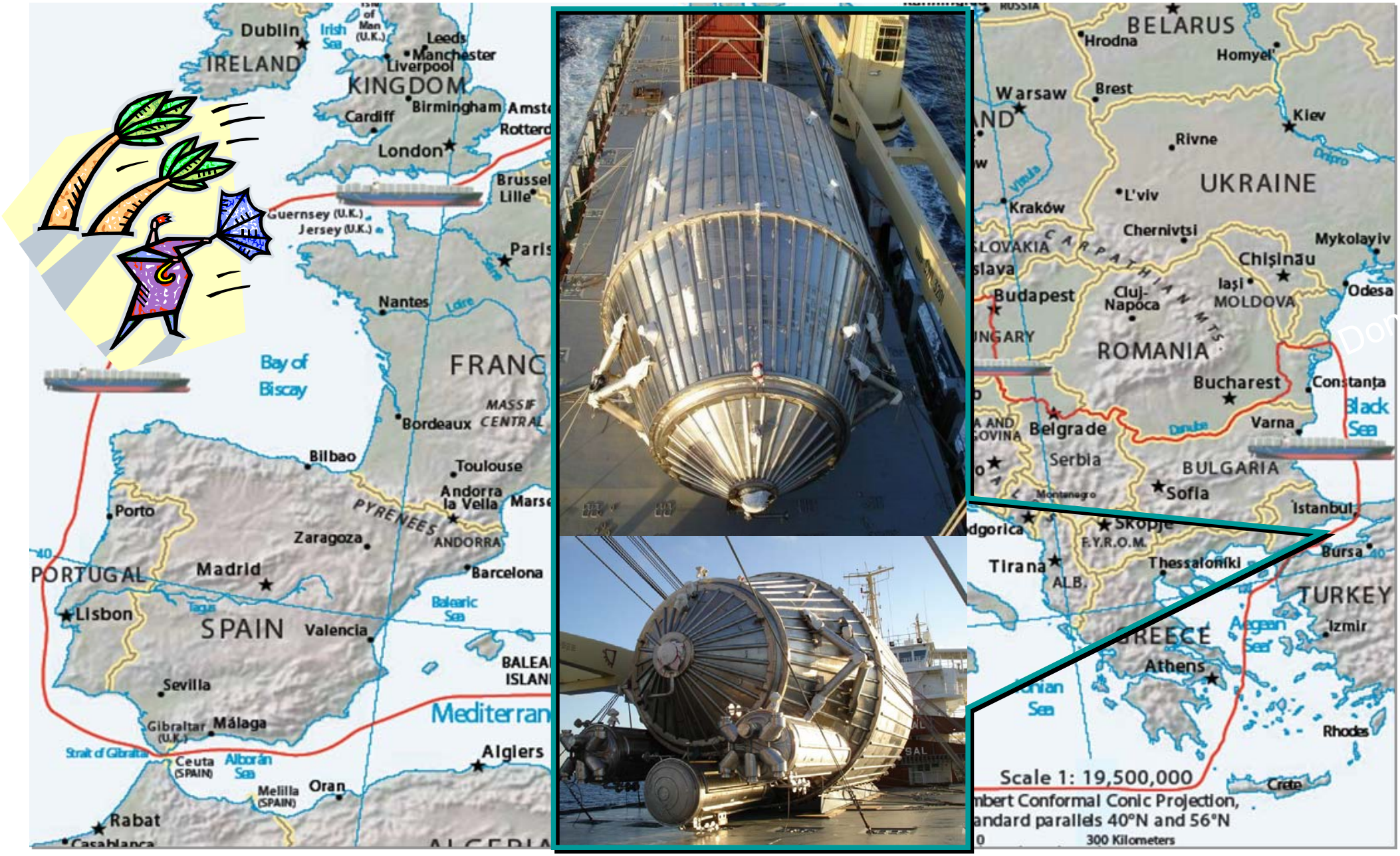


main spectrometer: transport

main spectrometer: transport

main spectrometer: transport

main spectrometer: transport



the final 7km: passing Leopoldshafen

November 25, 2006: after an 8800 km sea-going voayge the main Spectrometer was manoeuvred by an SPMT over 7km to the final destination at the KATRIN experimental halls…
(30.000 visitors)

arrival at Leimersheim ferry & reloading onto SPMT with heavy-duty crane

BBC NEWS

In pictures: photos of the year 2006

the final 7m, initial out-baking & UHV

steam blasting

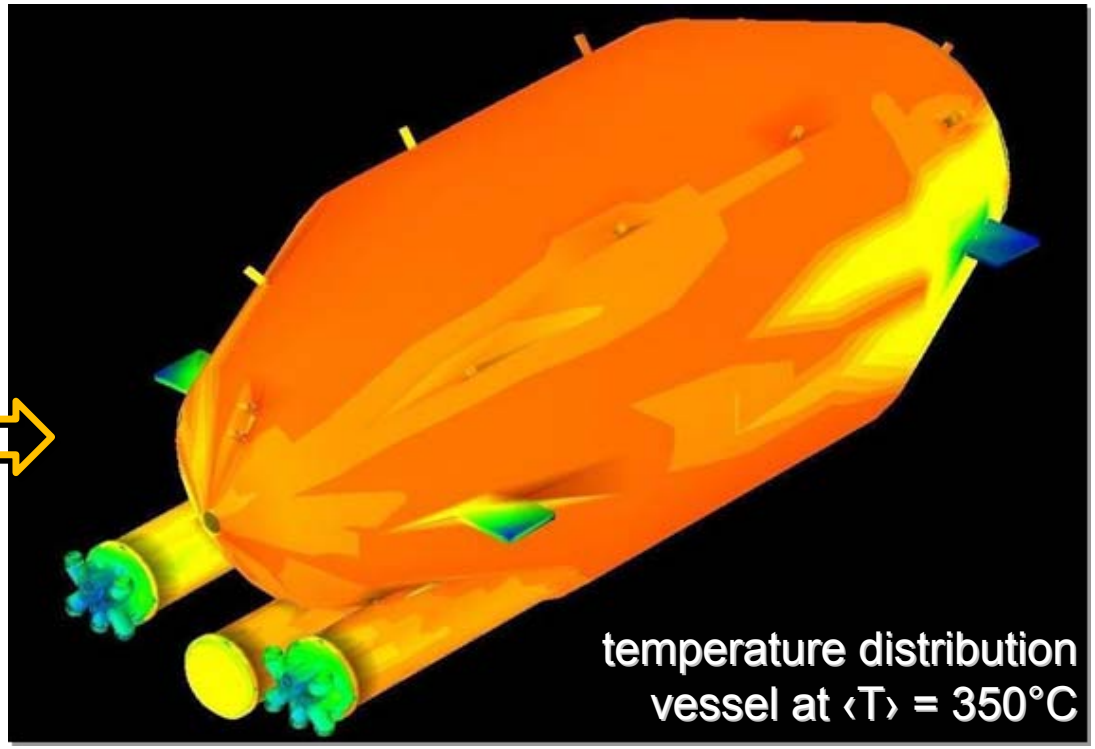
July 2007: initial UHV tests of vessel after out-baking with 6 TMPs

outgassing rate [T = 20°C]

1.18×10^{-12} mbar ℓ / cm² s

$p = 10^{-10}$ mbar

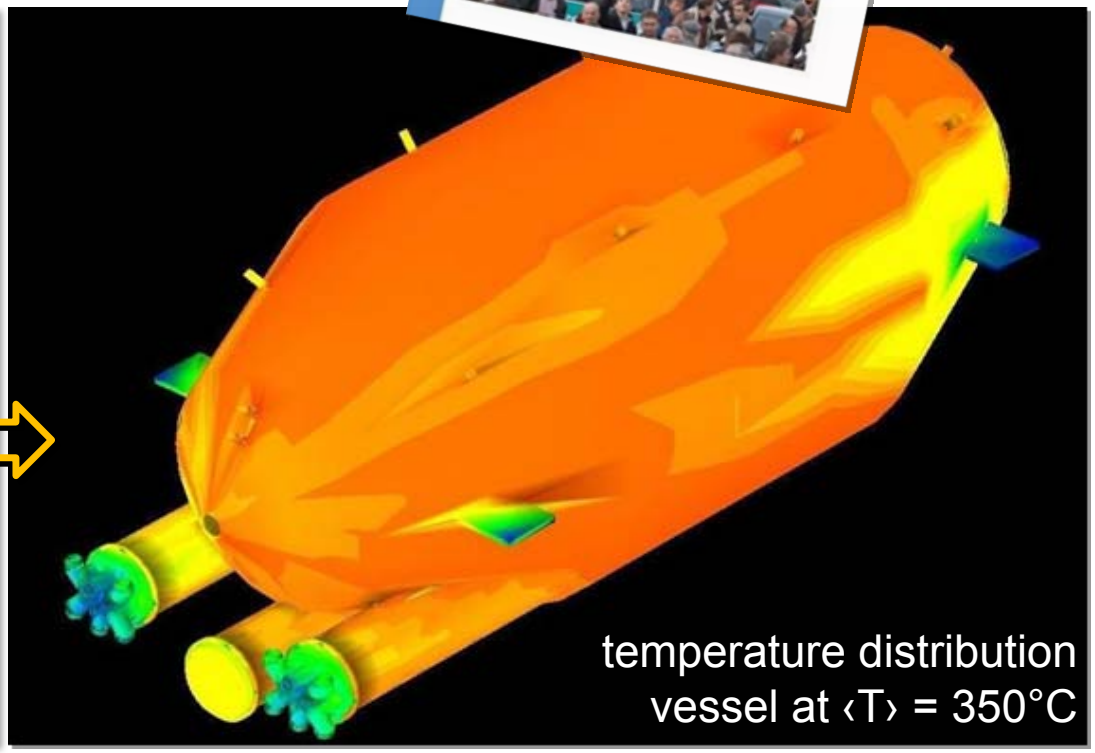
H_20 ↓ H_2



the final 7m, initial out-baking & UHV

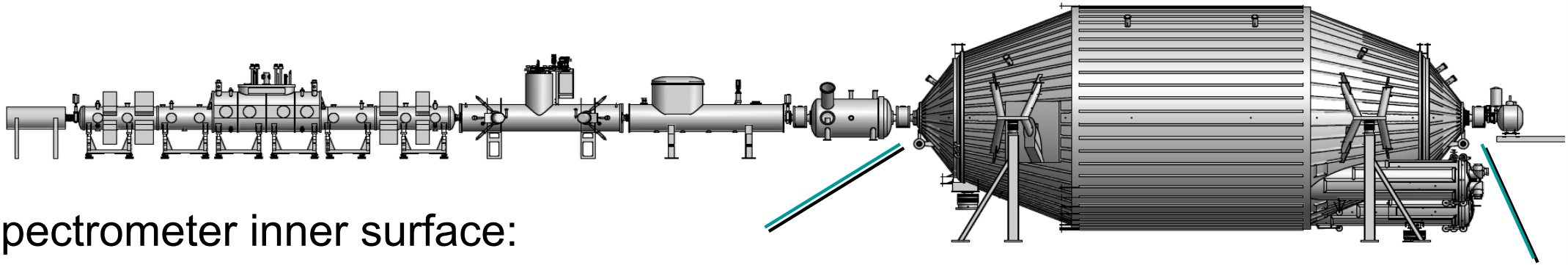
KATRIN
vacuum group

KIT board of directors

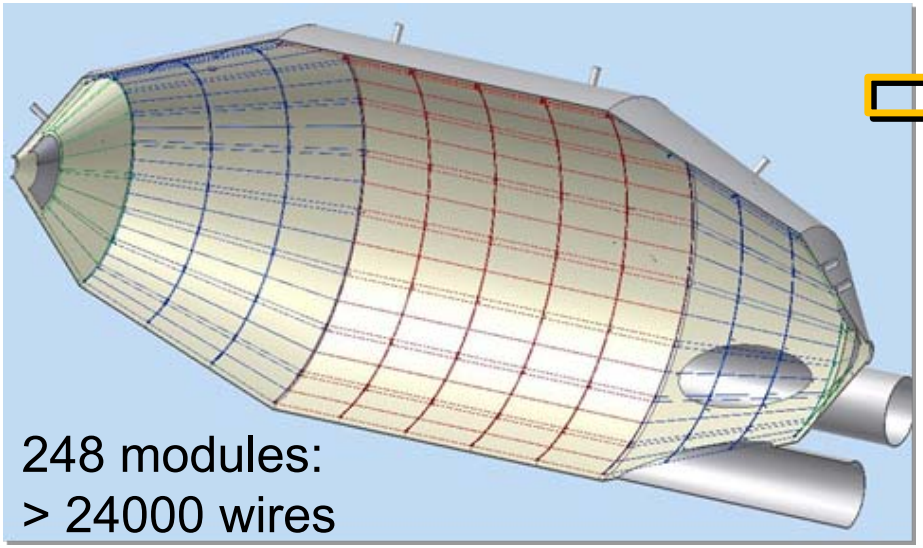


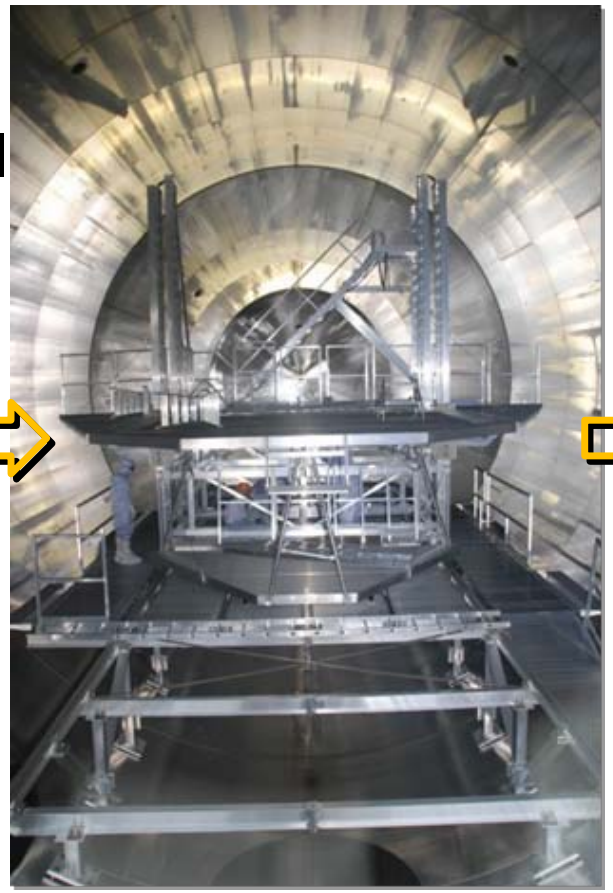
temperature distribution
vessel at ‹T› = 350°C

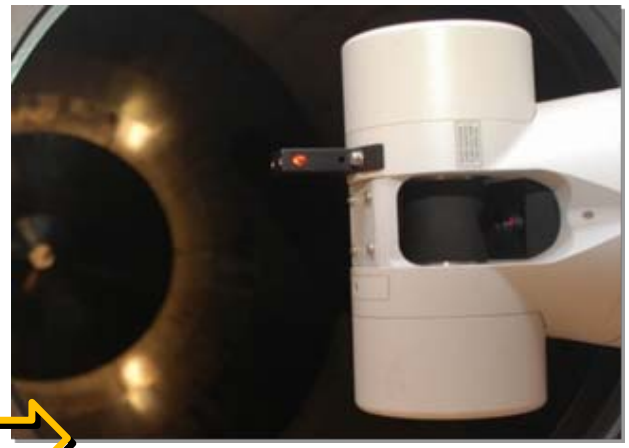
main spectrometer: inner electrodes

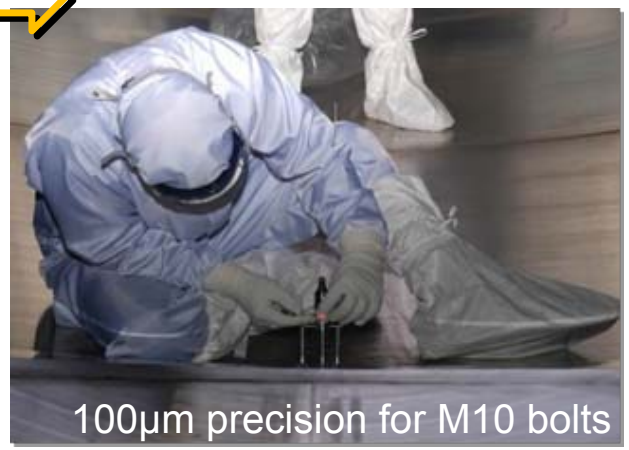


spectrometer inner surface:
covered by a ´massless´ inner wire-based electrode (2 layers)
- fine forming of retarding potential
- suppression of cosmic muon induced electron background

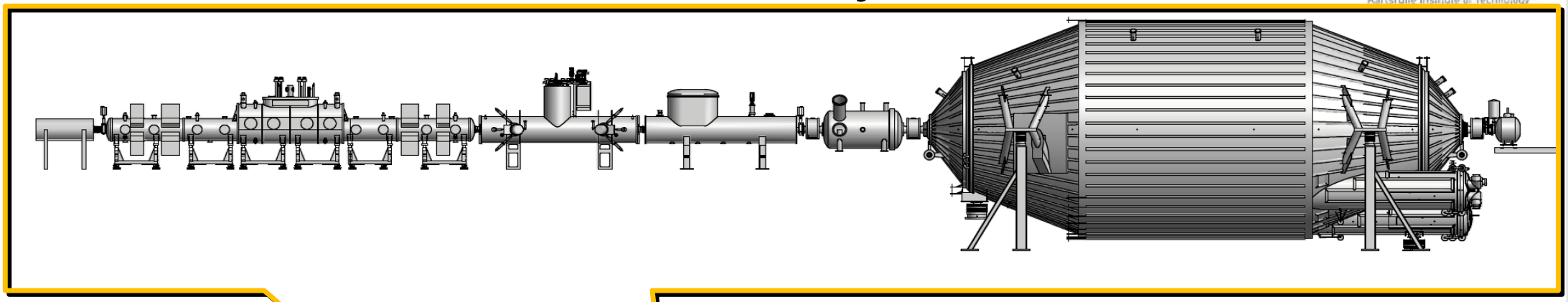


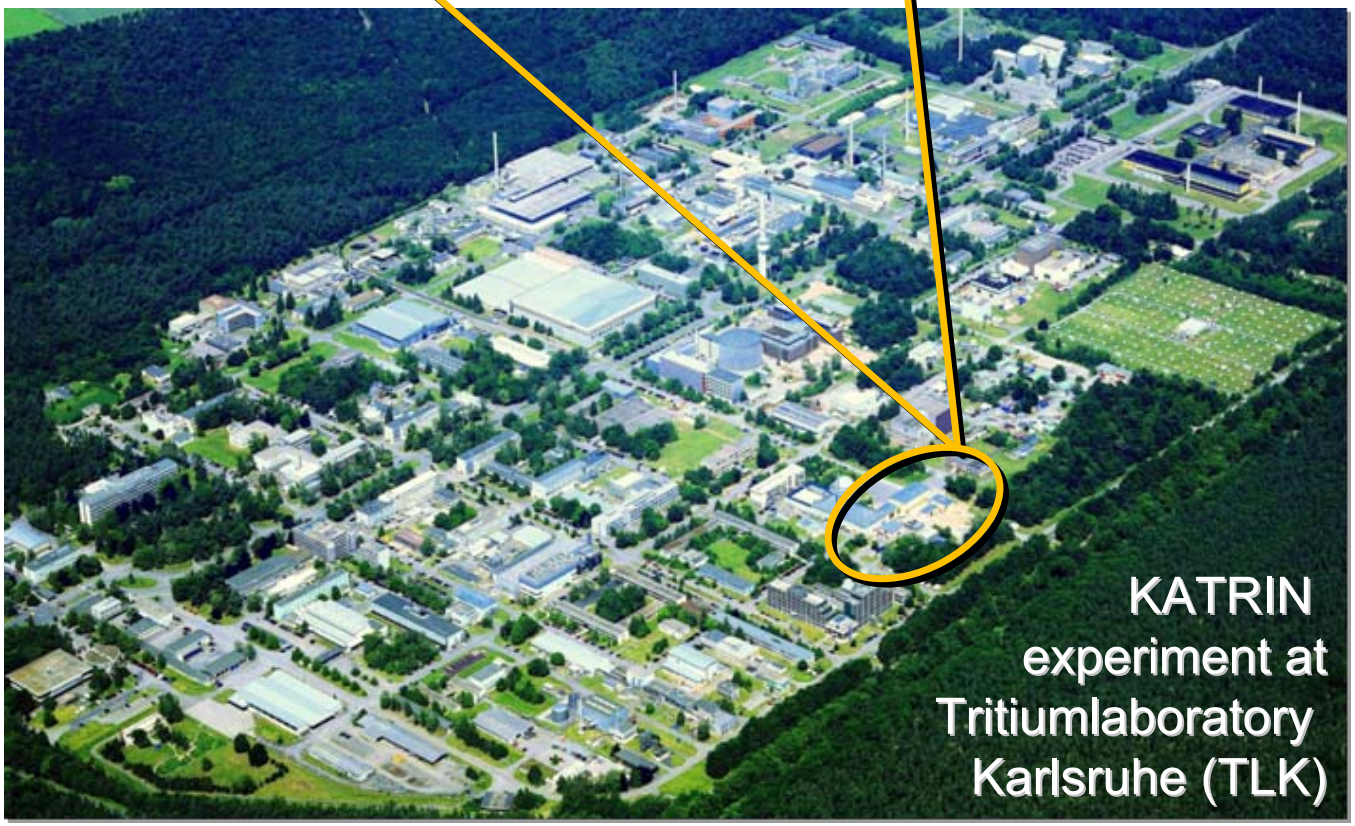






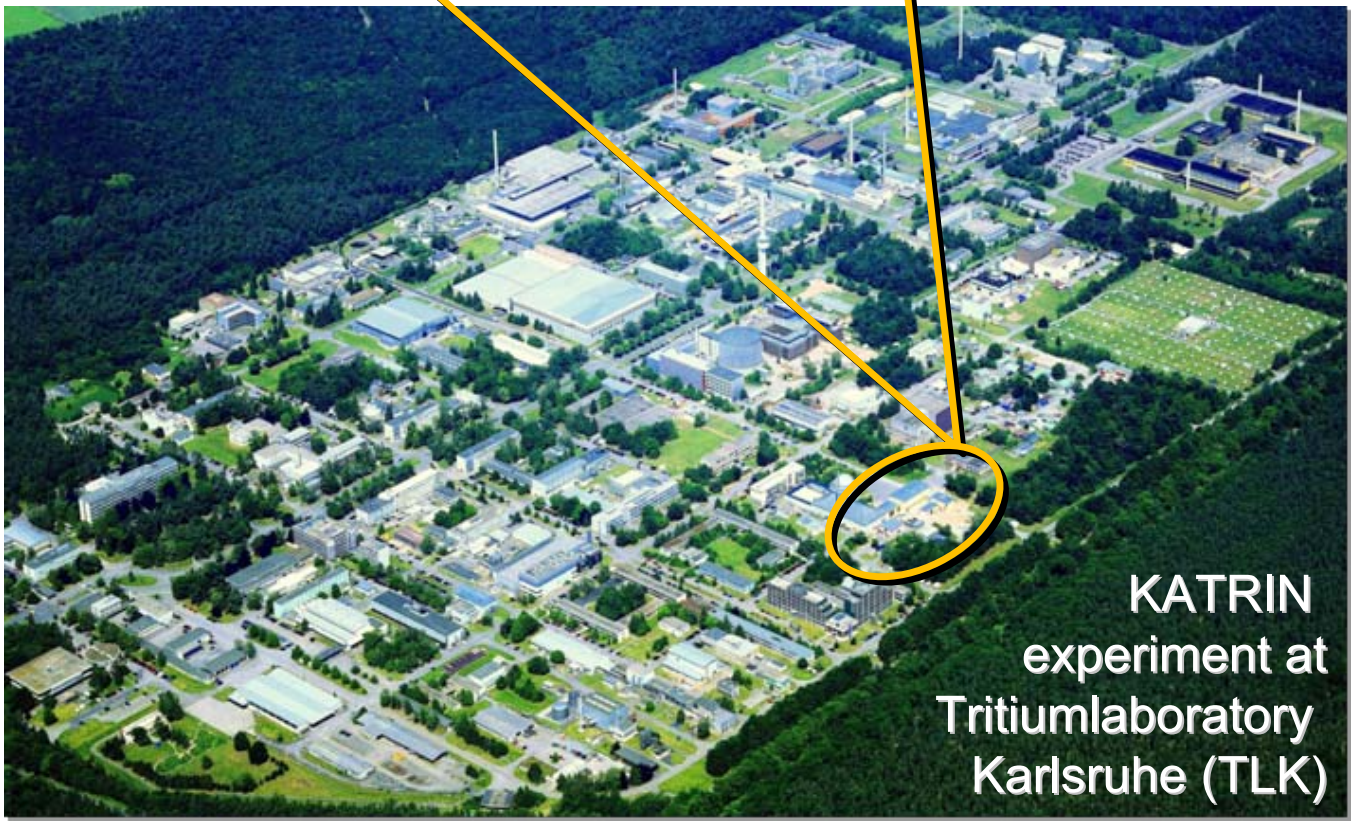
KATRIN at Tritium Laboratory Karlsruhe





all new experimental halls of KATRIN are completed & operational.

KATRIN at Tritium Laboratory Karlsruhe



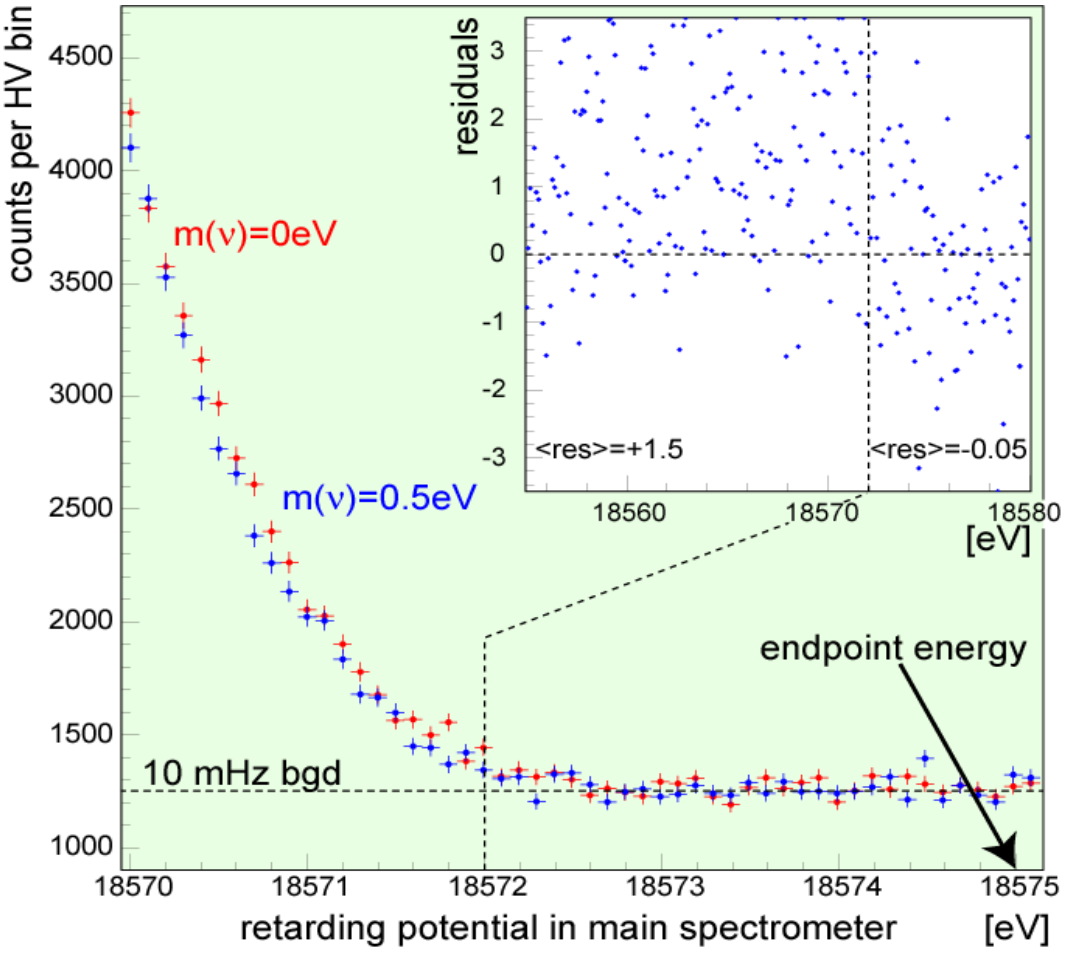
all new experimental halls of KATRIN are completed & operational.

tomorrow: visit of experiment

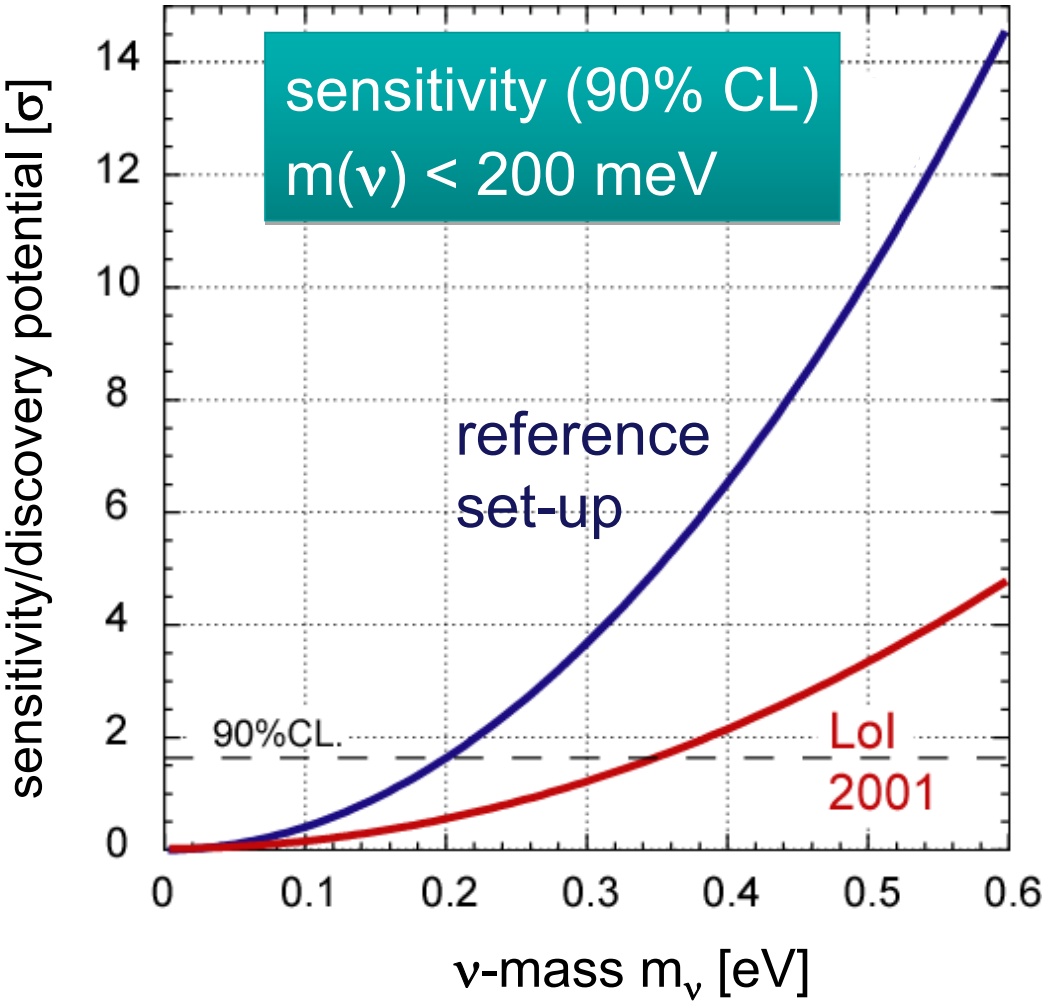
KATRIN – ß-spectrum & sensitivity

statistical and systematic errors will contribute equally to sensitivity

MC spectrum - 1 KATRIN fb-year



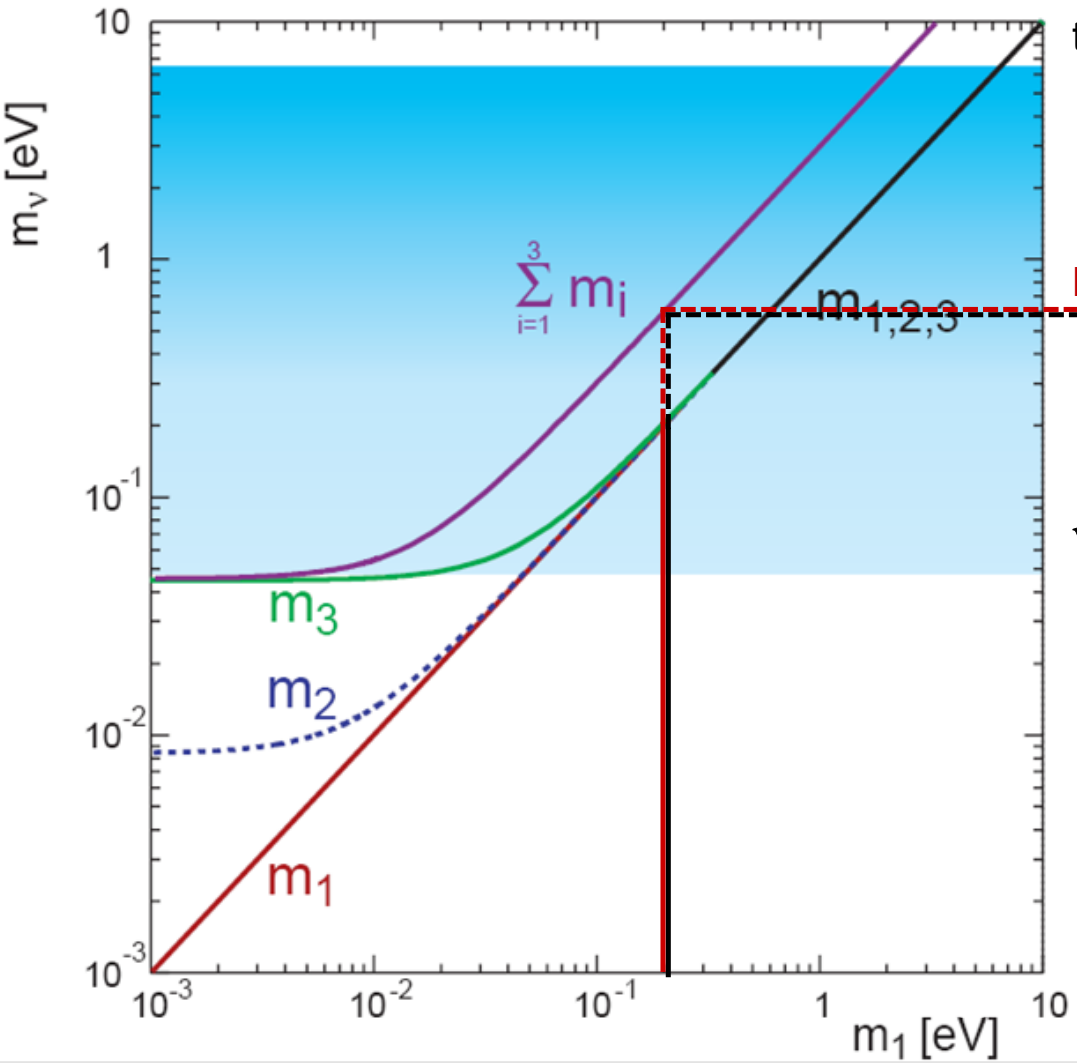
sensitivity - 3 KATRIN fb-yeats

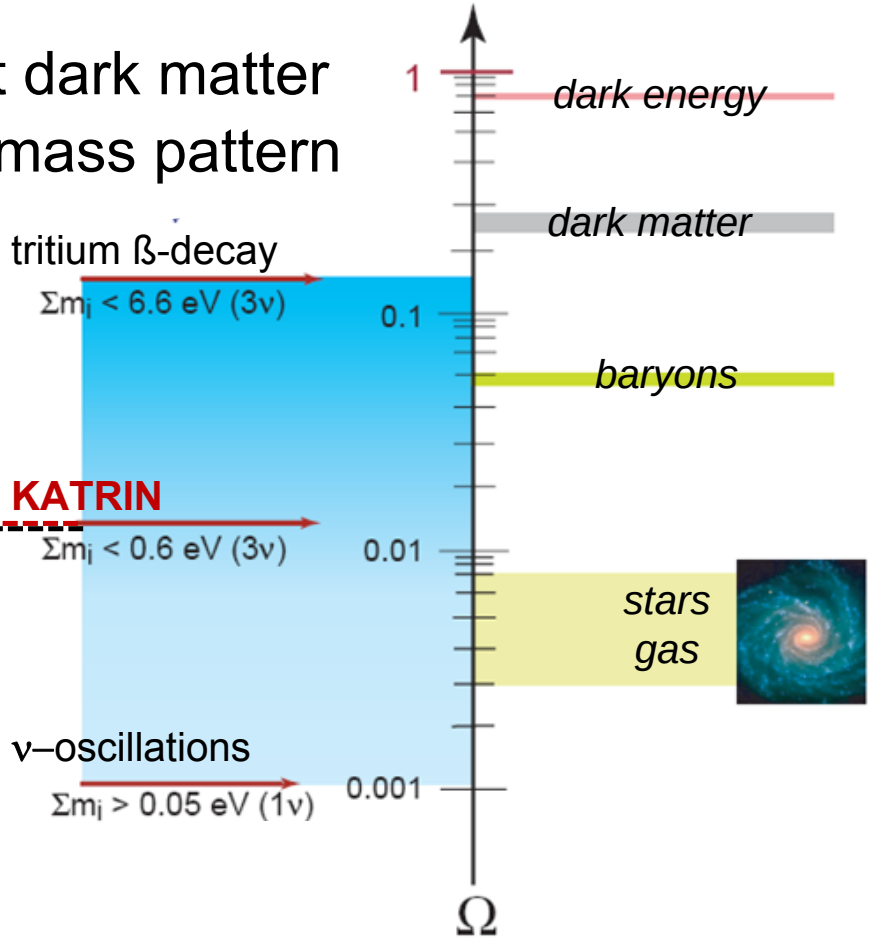


KATRIN impact on astroparticle physics

cosmic architects: fix relic-ν role as hot dark matter

microscopic keys: fix generic neutrino mass pattern





KATRIN : a key experiment for astroparticle physics

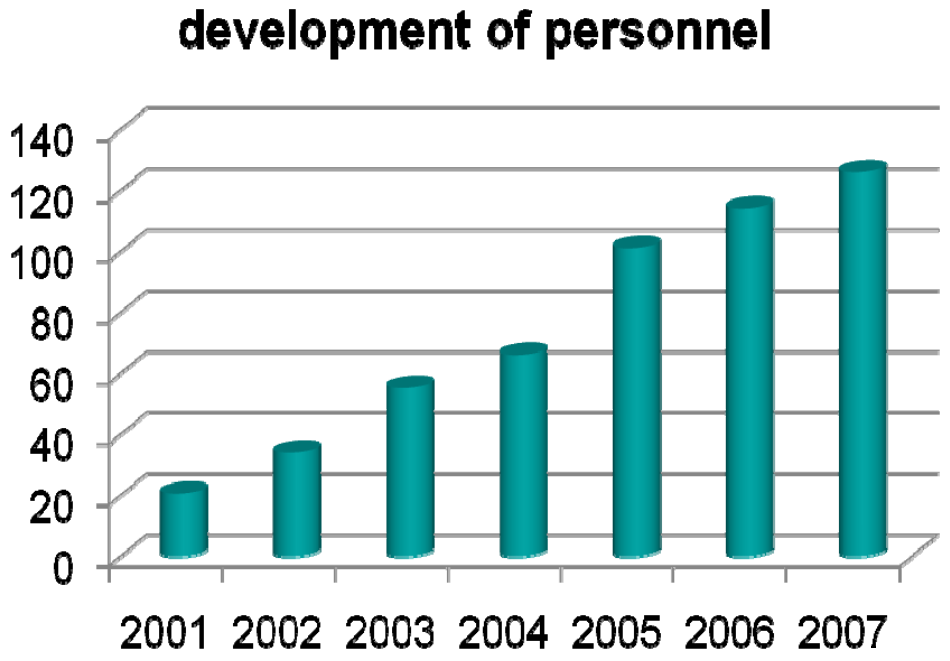
KATRIN Collaboration

uniting the world-wide expertise in tritium ß-decay experiments:

~140 Collaboration members (12 institutions from D, USA, GB, CZ, Russia)

~ **60% from KIT pool of expertise** (IK, EKP, ITP/TLK, IPE)

2012: begin of T_2 measurements



KIT – die Kooperation von Forschungszentrum Karlsruhe GmbH und Universität Karlsruhe (TH)

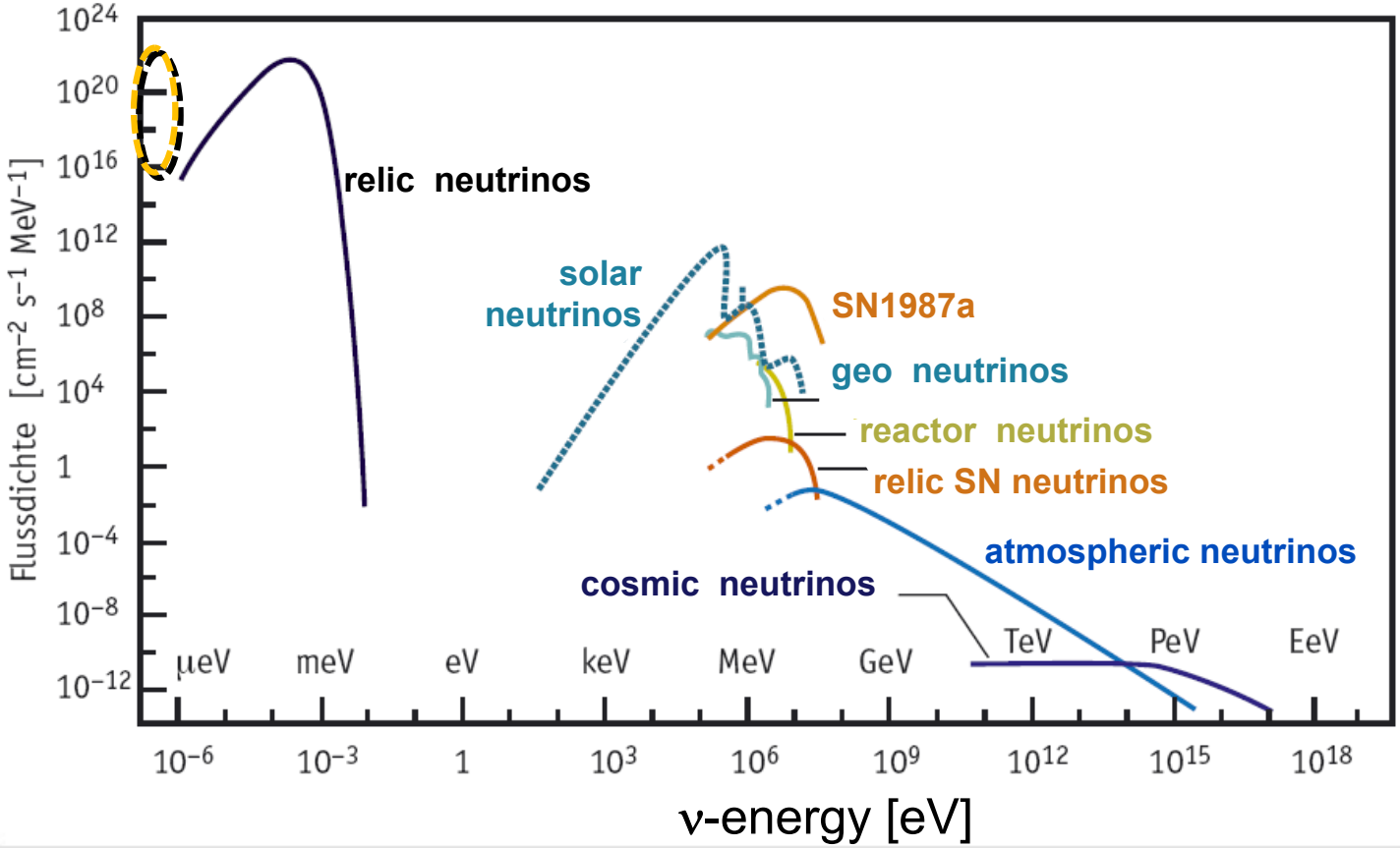
Universität Karlsruhe (TH) Forschungsuniversität • gegründet 1825

Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft

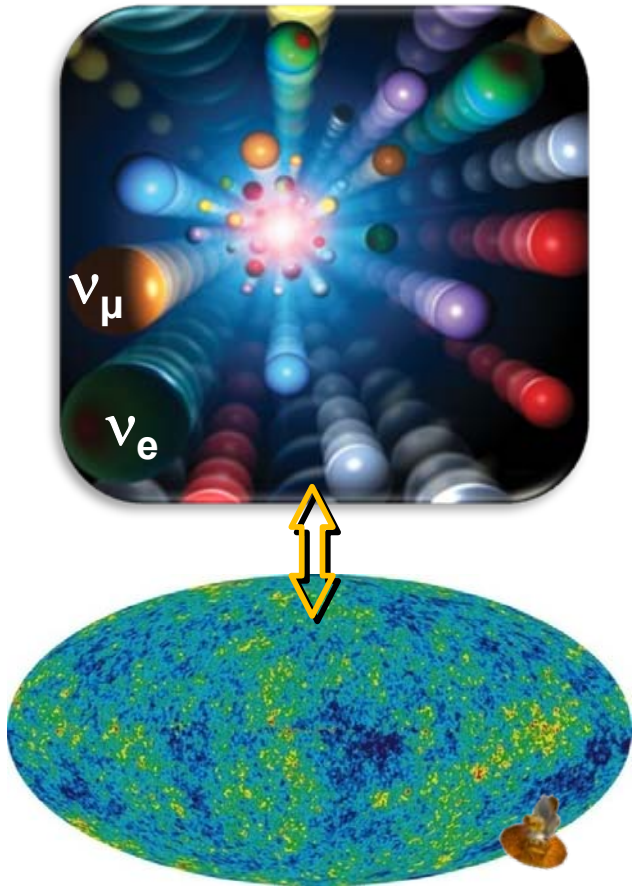
vision 2058: relic ν background

novel idea: **mapping the universe at t = 100 µs** after the Big Bang: capture of relic neutrinos on a ß-unstabile isotope (^{3}H):

$\nu_e + {}^3H \rightarrow {}^3He + e^-$ no threshold!



ν´s from the Big Bang (t = 0.1 s) CNB

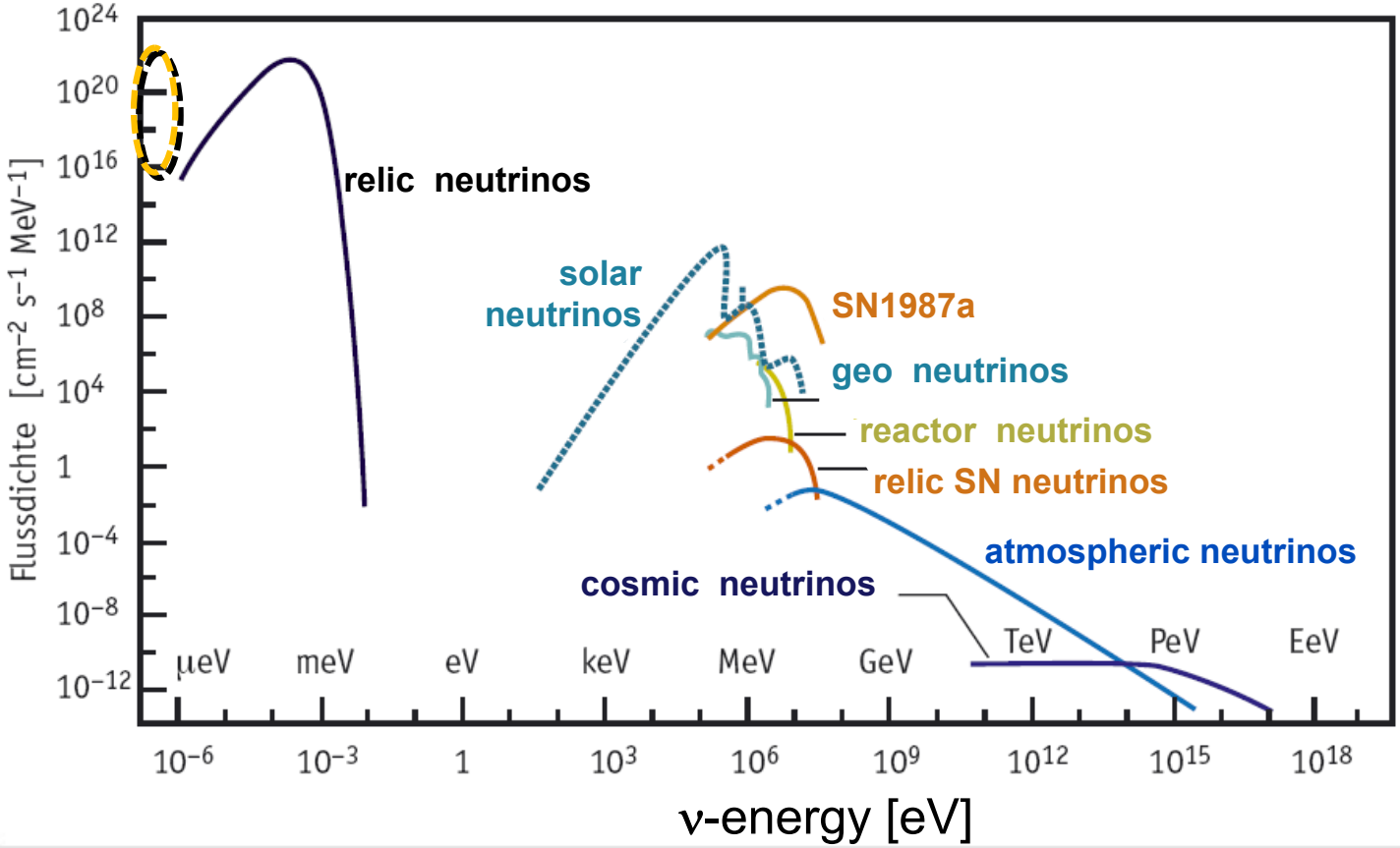


cosmic microwave background (t = 380.000 a)

vision 2058: relic ν background & KN100

novel idea: **mapping the universe at t = 100 µs**
after the Big Bang: capture of relic neutrinos
on a ß-unstabile isotope (^{3}H):

$\nu_e + {}^3H \rightarrow {}^3He + e^-$ no threshold!



i-paper

2058: Karlsruher Nuclide Chart will turn 100